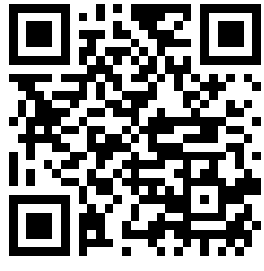


WT-1177

AEC Category: HEALTH and SAFETY
Military Categories: 22 and 42

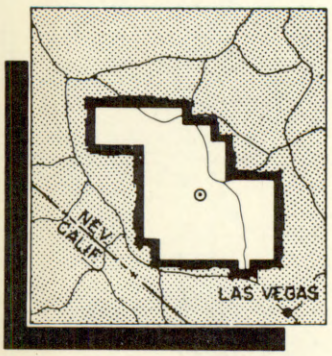
Operation TEAPOT

NEVADA TEST SITE

February – May 1955

Project 37.1

FACTORS INFLUENCING THE BIOLOGICAL FATE AND PERSISTENCE OF RADIOACTIVE FALL-OUT



CIVIL EFFECTS TEST GROUP

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PRINTED IN USA
Price $1.75. Available from the Office of
Technical Services, Department of Commerce,
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AEC Technical Information Service Extension
Oak Ridge, Tennessee

Report to the Test Director

FACTORS INFLUENCING THE BIOLOGICAL FATE AND PERSISTENCE OF RADIOACTIVE FALL-OUT

By

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January 1959

ABSTRACT

A study was made of the biological fate and persistence of radioactive fall-out relative to the physical characteristics of fall-out contamination, which varied with distance from Ground Zero (GZ). Special attention was given to the type of fall-out contamination on forage plants as representative of the internal emitters available to animals grazing in fall-out-contaminated areas.

Data indicated that the activity associated with the plant samples collected from areas within the various fall-out patterns was predominantly the result of external contamination by radioactive fall-out particles less than 44 μ in diameter. The degree of plant contamination was a function of the mechanical distribution of the particles less than 44 μ in size within a distance of 100 miles from GZ, which was in turn influenced by such conditions of weapon detonation as tower height and meteorology. The radioactive fall-out material on plant foliage was persistent, as evidenced by the activity remaining on leaves after washing in Versene and 0.1N HCl solutions and after mechanical shaking brought about by severe windstorms. An average of 21.6 per cent of the contamination on washed leaves was soluble in 0.1N HCl, which suggests that a similar percentage of the fall-out material ingested by grazing animals would go into solution in the digestive tract.

The tissue burdens of mixed fission products in animals sampled from fall-out-contaminated environments tended to decrease with distance from GZ in a manner similar to the degree of plant contamination. However, the beta activity per unit weight of femur tended to remain fairly constant to a distance of 140 miles from GZ. The thyroid showed a greater tissue burden of radioiodine at 60 miles than at either 12 or 140 miles from GZ.

The relative decrease of total beta radiation in tissues of native animals serially sampled from the same fall-out-contaminated environment in most cases did not markedly deviate from the theoretical beta radioactive decay rate of mixed fission products ($t^{-1.2}$). The beta activity per unit weight of femur, however, gradually increased until 3 days postshot and then decreased. The thyroid activity continued to rise throughout the 15-day sampling period. Iodine-133 is believed to contribute largely to the thyroid burden during the first 3 days following the detonation.

In all cases, animals with high activity in the gastrointestinal contents also had relatively high tissue burdens, whereas animals with low activity in the gastrointestinal tract had low tissue burdens. This suggested that ingestion was the principal source of fission products accumulated in tissues. The data further indicated that, in a population of animals grazing in a fall-out-contaminated environment, a rapid equilibrium between the absorbed activity and that passing through the gut may have been established within the first 2 days following fall-out. Data suggested that inhalation was a negligible path of uptake of fission products derived from weapons testing during, and for 12 hr immediately following, fall-out contamination.

The accumulation of fission products by grazing animals was related to particle size, and, because the plant acted as a selective collector for very small fall-out particles (predominantl less than 44 μ in diameter), the intake of radioactive bomb debris by animals during grazing tended to be similar over a great distance and appeared to be independent of total residual fall-out.

The amount of any specific fission product present in the environment is dependent in part upon the physical and chemical behavior of its parent during fall-out particle formation. Therefore, the amount of any specific isotope at any particular location within the fall-out pattern will be highly variable, and the occurrence of areas in which the biological accumulation of that isotope is high may be anticipated.

ACKNOWLEDGMENTS

The successful participation of Project 37.1 during Operation Teapot was dependent upon close cooperation with members of Projects 37.2 and 37.3 and upon the unusually high interest and effort of the personnel of Project 37.1, whose ability to turn the vicissitudes of routine field work into adventure kept morale high under very trying circumstances.

Particular acknowledgment is made to the following men, and to their employers, who participated at the Nevada Test Site for the duration of Operation Teapot:

Karl Herde, Savannah River Operations Office, AEC
Dr. Norman French, Idaho Operations Office, AEC
Walter Cool, Public Health Service, Bethesda, Maryland
Dr. Elliot Maynard, Atomic Energy Project, University of Rochester
John Bender, Radio-Ecology Division, Atomic Energy Project, University of California at Los Angeles (AEP-UCLA)
Walter McKibben, Radio-Ecology Division, AEP-UCLA
Dr. Robert Monroe, Radio-Ecology Division, AEP-UCLA
Dr. Leslie Bennett, Radiobiology Division, AEP-UCLA
Dr. David Howton, Biochemistry Division, AEP-UCLA
George Alexander, Industrial Hygiene Division, AEP-UCLA
George LeRoy, Radio-Ecology Division, AEP-UCLA
Robert Veomett, Radiobiology Division, AEP-UCLA
Paul Terasaki, Radio-Ecology Division, AEP-UCLA
William Slaton, Biochemistry Division, AEP-UCLA
Bruce Kowalewsky, Radio-Ecology Division, AEP-UCLA
Lewis Kurpjweit, Pharmacology and Toxicology Division, AEP-UCLA
Gail Vosberg, Pharmacology and Toxicology Division, AEP-UCLA

Field samples are only as good as the laboratory analysis to which they are subjected. For the laboratory support to the field effort, we are particularly indebted to Dr. Hideo Nishita, Radio-Ecology Division, AEP-UCLA, who directed and executed most of the experiments involving plant material, and to Janice Taylor from the same division for her part in the processing of animal samples. These persons were ably supported by the following:

James Watson, Radio-Ecology Division, AEP-UCLA
Barbara Gillooly, Radio-Ecology Division, AEP-UCLA
Allen Steen, Radio-Ecology Division, AEP-UCLA
Rhoda Devick, Pharmacology and Toxicology Division, AEP-UCLA
Patricia Peel, Pharmacology and Toxicology Division, AEP-UCLA
Dorothy Fillerup Long, Biochemistry Division, AEP-UCLA
Marshall Schlachter, Biochemistry Division, AEP-UCLA
Patricia Spain, Pharmacology and Toxicology Division, AEP-UCLA
Philip Noyes, Pharmacology and Toxicology Division, AEP-UCLA
William McCormick, Pharmacology and Toxicology Division, AEP-UCLA

Susan Ellsworth, Industrial Hygiene Division, AEP-UCLA
Virginia Debly, Pharmacology and Toxicology Division, AEP-UCLA
Marion Hubble, Radiobiology Division, AEP-UCLA
Edward Miller, Pharmacology and Toxicology Division, AEP-UCLA
James Scanlan, Radio-Ecology Division, AEP-UCLA
William Rhoads, Radio-Ecology Division, AEP-UCLA
Chandler North, Subtropical Horticulture Department, UCLA

In addition, we wish to express our appreciation to Dr. Arthur Wallace and to the Subtropical Horticulture Department, UCLA, for providing the necessary glasshouse facilities in which the domestic crop plants used for exposure to primary fall-out materials were grown.

We are grateful to Rose Puntenney, Radio-Ecology Division, AEP-UCLA, for the appearance of this report in its final form, for her tireless efforts in typing the manuscript, and for her patience and understanding when changes and corrections in assembling this report have been necessary.

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Chapter 1

INTRODUCTION

1.1 OBJECTIVES

The purpose of this investigation was to study the factors influencing the biological fate and persistence of radioactive fall-out materials in areas adjacent to the Nevada Test Site (NTS). Data have been obtained pertaining to the following phenomena:

1. The biological accumulation of radioactive materials derived from nuclear detonations as functions of distance of the sampling station from Ground Zero (GZ), radioactive particle-size distribution, and fractionation of fall-out material as it may vary with distance from GZ. These data included determinations of total uptake of fission products in animals, sites of retention, rates of clearance, and isotopic identification of some contaminants.
2. The persistence of radioactive fall-out material on plants and in animals living in contaminated environments.
3. The availability of fall-out materials to plants under various conditions of contamination. These studies included cropping of contaminated soils, foliar retention, and uptake of radioactive materials from soils treated with organic matter exposed to fall-out materials.
4. Evaluation of inhalation as a significant phenomenon in the uptake of radioactive fall-out in actual fall-out areas.
5. The percentage distribution of the total-body burden of certain fission products in the tissues of animals exposed to fall-out at various distances from GZ.

1.2 BACKGROUND

Previous studies of the biological fate and persistence of radioactive fall-out resulting from continental detonations of nuclear weapons have revealed the following:

1. Radioactive fall-out is immediately available to animals and is accumulated and/or metabolized in microcurie levels of concentration.[1,2]
2. Radioactive fall-out is persistent in the environment over a period of years.[2–4]
3. Radioactive substances resulting from fall-out contamination are persistent in metabolic systems for a period of years, apparently in equilibrium with the environment.[2–4]
4. The total biological burden of fission products 1 year or more after initial contamination by radioactive fall-out is similar (within the fall-out pattern) throughout a distance of at least 138 miles from GZ. There is a tendency for the body burden of certain radioactive elements in native rodents to increase with distance from GZ.[2,5,6]

These data and studies of the physical and chemical nature of fall-out material[7] have led to the assumption that biological availability of fall-out material is a function of the physical state of fall-out, the isotopes present, and the method of biological uptake (i.e., ingestion, inhalation, root uptake, and foliar absorption).

Fall-out materials resulting from continental detonations have been characterized as particulate in nature, consisting principally of fused, siliceous or magnetic beads; however, there are exceptions.[8,9] There is a real possibility that large particles as such do not contribute appreciable amounts of available radioactivity for uptake by plants and animals,[1,2] but these large particles may act as carriers for smaller and more readily available particles (which may range in size from molecular to a few microns) adsorbed on their surfaces. These adsorbed particles may be easily dissociated from the large particles by moisture in the air, on the ground, or in the lungs or digestive tracts of animals. There is no real evidence that this does not account for the apparent solubility of some large fused particles studied. This supposition is borne out by the trail of radioactive material left by large particles bouncing across a gummed paper,[10] by the radioactivity measured as soluble in rain water at Hanford Works,[11] by the presence of very fine particles within a few miles of GZ,[7] and by the high incidence of radioiodine within a few miles of GZ.[2,12]

Evaluations of human hazards resulting from fall-out contamination are generally made on the assumption that fall-out materials, whatever their physical nature or distribution, are homogeneous and follow the typical mixed-fission-product decay function ($t^{-1.2}$). However, physical characteristics of fall-out particles, such as solubility, have been shown to vary from 2 to 75 per cent.[8] Some particles are magnetic; others are not.[8,9,13] Fractionation of fission products among fall-out particles and as a function of particle size has also been demonstrated (references 7, 9, and 14-16). The gamma decay rate of fall-out material has been observed to deviate significantly from the $t^{-1.2}$ decay factor.[9] These observations tend to support an opposite contention: Fall-out materials are not homogeneous with regard either to physical state or isotopic content. With such variability, it is doubtful if the present data are adequate for the proper evaluation of biological hazards, particularly if it is realized that the concentrated effort of describing the nature of fall-out material has been restricted chiefly to large particles, whose relative biological significance is thought to be low.

It has been stated that biological availability is a function of the solubility of fall-out materials.[2,12] This suggests that availability of fission products from fall-out particles is a function of their surface/mass ratio; or, in other words, the smaller the particle, the greater its potential solubility and biological significance. It has been demonstrated by particle-size analysis of fall-out materials that a proportionately larger number of small particles occur with increasing distance from GZ.[7] It then follows that the solubility (biological availability) of fall-out materials may actually increase with distance, although the total radioactivity falls off very sharply. The validity of such an assumption is supported by data obtained during Operation Upshot-Knothole which showed that animals collected 31 miles from GZ contained greater amounts of radioactive material than animals sampled 16 miles from GZ, although the environment at 31 miles received much less contamination.[2] Data from four stations between Yucca Flat and St. George, Utah, revealed that the accumulation of radiostrontium in animal bones as measured 1 year after contamination was approximately five times greater in the St. George area (130 miles distant) than within 5 miles of GZ.[6]

The biologically significant areas in terms of exposure to external radiation may be relatively limited in time and distance from GZ. However, the effects of internal radiation as a result of absorbed and/or metabolized radioactivity must be considered in terms of the entire fall-out pattern over whatever area or distance it is detectable. The time span of concern will be dictated by the biologically significant isotopes of long half lives. At the present time, radiostrontium (Sr^{90}) and radiocesium (Cs^{137}) are the critical elements because of their relatively high fission yield or abundance, their biological availability, and their long half lives. It has been demonstrated, however, that the total metabolized radioactive materials in animals 1 year after contamination cannot be accounted for by radiostrontium or radiocesium alone. Due attention must be given the short and medium half-life isotopes that may be contributing to the total-body load; notable examples are radioiodine, radiobarium, and radioruthenium.[17,18] Except for the original Alamogordo survey,[3,4] data are conspicuously absent regarding levels of residual alpha radiation resulting from fall-out contamination.

It is possible that many of the data reported which discount inhalation as a significant path of uptake are the result of inadequate sampling of air-borne material. It is interesting to note that reports of previous air-sampling programs usually are prefaced by a discussion of the

inadequacies of the samplers used. Apparently no sampler has yet been designed for field use which will secure a random sample of an aerosol. The fact that inhalation may be worthy of a detailed study was suggested by experiences during Operation Buster-Jangle.[10] Although measured air-borne concentrations were considered below the maximum permissible level, the following statement was made:

> Of particular interest in both Jangle shots was the amount of extremely radioactive air-borne dust which could pass a given point without leaving any significant deposition on the ground. It is well-known that the dust cloud following the second shot went to the north with a low velocity wind and seemed to hang in the valleys. However, it is not so generally known that in the late afternoon the wind reversed and the dust returned and passed directly over the Control Point. By this time it had a mean particle size of approximately 0.1 μ but was sufficiently active in raising the background so that all counting activities had to be discontinued for the night. Filter papers on which some of the material was collected were too hot to count even on the following day.

Muzzled animals that were exposed during Operation Jangle shots at 2000 and at 5000 ft from GZ seemed to reflect a minimum uptake.[1] From the report, it appears that the animals were not subjected to this second exposure in the late afternoon. If not, then a minimum uptake from the first exposure period would be predicted (particularly from inhalation) on the basis that the smaller particles of inhalable size were carried farther from GZ into areas where there were no muzzled animals placed for exposure. To elucidate further the significance of inhalation of fall-out particles as a contributing source of uptake of radioactive materials, it appeared that further inhalation studies should be conducted by exposing experimental animals to fall-out materials at various distances from GZ. Furthermore, it seemed important to obtain quantitative data from the field to describe just what part of the body burden can be attributed to inhalation and whether this fraction changes with distance.

Related to the problem of uptake of radioactive fall-out materials through ingestion by animals is the question of foliar retention of radioactive materials by plants. In both cases, fall-out particle size and/or the fission products adsorbed on it may be the principal influencing factors. Previous investigations by this laboratory of native plants contaminated with fall-out have revealed the presence of persistent radioactive materials of which significant amounts can be washed from the plant foliage, thereby suggesting that the principal source of contamination is retained externally on leaf surfaces in the form of particulate matter.[2,17] Studies of plants grown on soil flats contaminated by direct exposure to fall-out and plants grown under greenhouse conditions on soils artificially contaminated with radioactive fall-out materials have shown that certain amounts of fission products will be accumulated internally by plants.[8] The factors influencing these phenomena require further definition.

A leaf surface may be considered as a special type of collector, with the efficiency of collection depending upon the characteristics of the leaf surface, namely, sticky, hairy, rough, or smooth. It is probable that plants contaminated by radioactive fall-out retain in significant amounts only those particles below a certain maximum size instead of equal contributions from the total particle-size range. Because of the decrease in average particle size with distance, similar types of leaves should tend to retain radioactive fall-out more representative of the total environmental contamination with increasing distance from GZ. Such a phenomenon may result in a selective mechanism whereby only a certain maximum particle size is retained by plants over a relatively large distance. If particles retained on leaf surfaces have similar physical and chemical properties and are the principal radioactive contaminants ingested by grazing animals, then one would predict that the total-body burden of radioactive materials in animals grazing in fall-out areas would be similar over a wide range of conditions.

Experience during Operation Upshot-Knothole led to the conclusion that the total-body burden of radioactive fission products in animals exposed to fall-out could be almost entirely accounted for as a result of ingestion of range forage.[2] Therefore, if this be true, it then becomes important to determine whether or not specific size fractions of fall-out are collected on forage plants; if so, in what concentrations; and, further, what the biological significance of the contamination is to animals grazing the area and to the plant itself in terms of foliar absorption.

1.3 OPERATIONS

Biological sampling conducted during Operation Teapot was done under the administrative direction of Project 37.1, Program 37, of the Civil Effects Test Group (CETG). It should be emphasized that biological data have limited value without detailed physical measurements of fall-out describing the total environmental contamination. Similarly, the physical measurements lose perspective without correlation with biological fate and effect. Therefore, Program 37 consisted of three closely integrated projects: (1) Project 37.1, primarily concerned with the biological fate and persistence of radioactive fall-out; (2) Project 37.2, primarily concerned with the physical and chemical properties of fall-out and the factors influencing fall-out distribution; and (3) Project 37.3, primarily concerned with the critical evaluation of inhalation as a path of uptake of radioactive fall-out materials.

The persistence of radioactive fall-out contamination in areas adjacent to NTS is a part of the continuing research program of the Environmental Radiation Division, Department and Laboratories of Nuclear Medicine and Radiation Biology, University of California at Los Angeles (UCLA). It is anticipated that periodic sampling of contaminated environment in this area will continue as long as practical to extend studies initiated in 1951.

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Chapter 2

PROCEDURES

2.1 SAMPLING AREAS

Native soil and plant and animal samples were collected from areas adjacent to NTS out to distances of about 200 miles from GZ. Three to four sampling areas were oriented along the predicted and actual midlines of fall-out patterns from Tesla, Apple I, Met, and Apple II detonations. The midline of a fall-out pattern was defined as a line extending from GZ to the most distant station which joins the highest levels of radiation measured at each distance from GZ.

Environmental conditions of the sampling areas varied from those of flat desert-type valleys to dense piñon pine and juniper forests characteristic of the northeastern quadrant adjacent to NTS. In some cases, sampling areas were adjacent to such agricultural centers as Alamo, Nevada, and St. George, Enterprise, and Cedar City, Utah. A typical sampling station showing the prelocation of soils, plants, and animals is shown in Fig. 2.1, and Fig. 2.2 shows the types of soil flats and animal restraining cages used for the prelocation studies.

2.1.1 Soils

The soils in the virgin areas are relatively young and underdeveloped and vary markedly in their physical and chemical characteristics. The surface soils are typically pinkish gray, light grayish brown, or gray in color, and low in organic matter. The subsoils are somewhat lighter in color and may be calcareous. The alluvial valley soils have become moderately to highly saline, with pH levels of 7.5 to 8.5, through an accumulation of soluble salts under arid conditions. Most of the land is presently used only for livestock-grazing range with low carrying capacity.

2.1.2 Plants

Native plant species collected from one or more of the sampling areas are listed in Table 2.1 according to genus, common name, and some leaf-surface characteristics. Some examples are shown in Figs. 2.3 and 2.4.

In most of the sampling areas, the perennial plants remain dormant until late in April. Most of these shrubs are grazed by livestock, and their seeds, bark, and tender succulent shoots provide food for the rodent and rabbit population. Annual plants begin germination in late April or early May, depending on the availability of moisture. The foliage of many of the plants provides numerous crevices in which fall-out materials may lodge. This is particularly true of the scalelike foliage of juniper and the sticky resinous foliage of creosote bush.

2.1.3 Animals

Small animals found in most sampling areas included kangaroo rats, *Dipodomys;* white-footed mice, *Peromyscus;* and jack rabbits, *Lepus*. Also present in many localized areas were

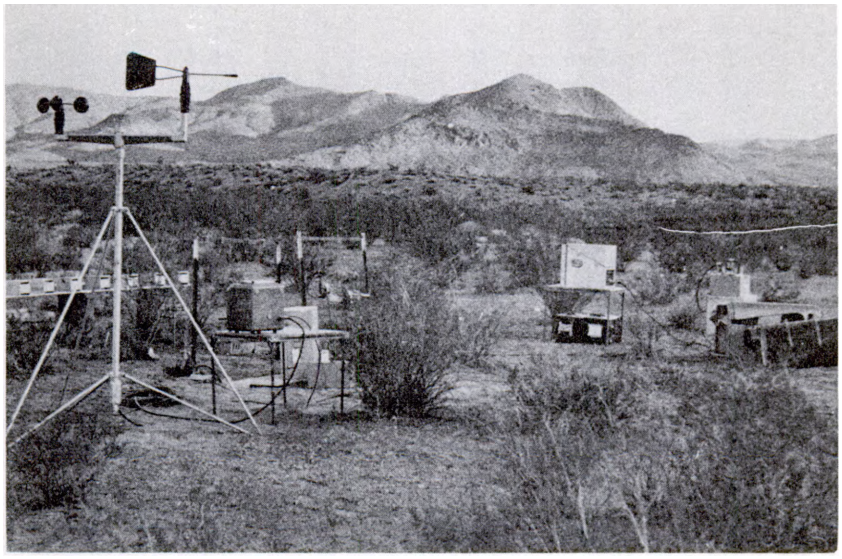


Fig. 2.1—Typical sampling station showing the position of prelocated soil, plant, and animal specimens (left background) relative to the air-sampling equipment of Project 37.2.

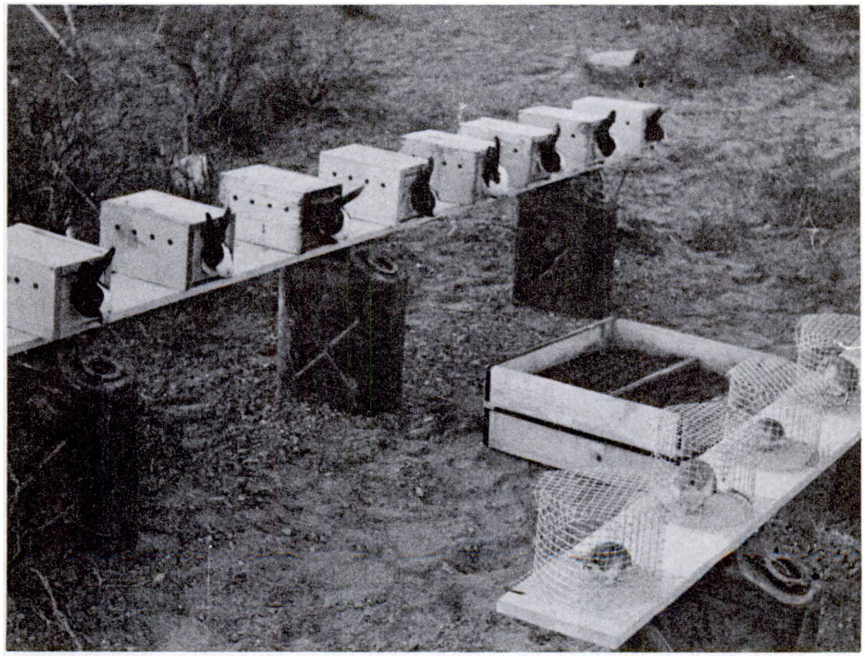


Fig. 2.2—Project 37.1 sampling station showing the types of soil flats and animal restraining cages used for prelocation studies.

TABLE 2.1 — DESCRIPTION OF PLANT SPECIES SAMPLED IN THE ENVIRONS OF NTS

Genus	Common name	Leaf-surface characteristics
Anemone	Desert windflower	Scurfy (branlike scales)
Aquilegia	Columbine	Scurfy
*Artemisia**	Sagebrush	Dense, matted, unbranched hairs and glands
Atriplex	Shad scale	Scurfy
Ceanothus	Deer brush	Bald or glabrous (not hairy)
Chrysothamnus	Rabbit brush	Covered with soft woolly hairs
Coleogyne	Blackbrush	Surface covered with fine white hairs
Brassica	Mustard	Short, dense hairs, scurfy
Ephedra	Mormon tea	Scalelike, muriculate branches
Eriogonum†	Wild buckwheat	Dense, stiff, unbranched hairs
Erodium	Fillaree	Scattered hairs, concentrated toward margin
Helianthus	Sunflower	Hairs on veins and at margins
Larrea	Creosote bush	Very resinous
Lepidium	Peppergrass	Glabrous and glaucous
Mirabilis	Four-o'clock	Smooth, glabrous surface
Oenothera	Desert primrose	Dense, long, unbranched hairs
*Oryzopsis**	Bunch grass	Sparse barblike hairs
Penstemon	Scarlet bugler	Smooth waxy surface
Sphaeralcea†	Bush mallow	Dense stellate hairs
Stanleya	Desert plume	Rough epidermis, no hairs
Juniperus	Juniper	Scalelike, imbricated
Viola	Violet	Smooth glands at base

* See Fig. 2.3.
† See Fig. 2.4.

cottontail rabbits, *Sylvilagus;* pocket mice, *Perognathus;* wood rats, *Neotoma;* and antelope ground squirrels, *Citellus.* In a few areas were found western harvest mice, *Reithrodontomys megalotis;* southern grasshopper mice, *Onychomy torridus;* and kangaroo mice, *Microdipodops.*

Of these small animals, all except the rabbits and ground squirrels normally spend the daylight hours in their burrows, which they usually plug with soil. These nocturnal species feed mainly on the seeds of the native plants. The ground squirrels have similar food habits, but they normally forage during daylight. Rabbits feed mainly during the early morning and evening hours on succulent vegetation, and they may range over a half-mile-square area or more.

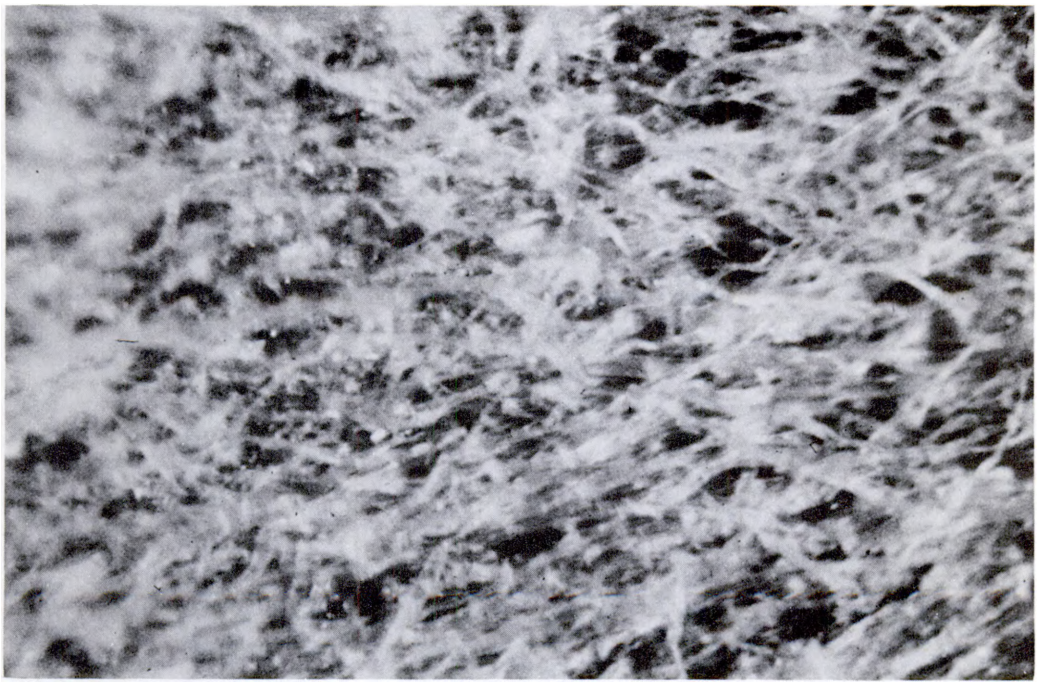
The nocturnal burrowing forms will rarely be aboveground during the period of fall-out from test shots detonated predawn, and, since they live underground during daylight, they will be shielded from the radiation field during the acute period of contamination. In contrast, rabbits are exposed continuously when they are in fall-out patterns. The foraging activity of jack rabbits, however, may take them in and out of maximum fall-out areas during the first several weeks, making it difficult to estimate an integrated radiation dose over an extended period of time.

2.2 PLANT AND SOIL EXPERIMENTS

2.2.1 Sampling and Radioassay of Native and Domestic Plants and Soils Exposed to Fall-out Materials

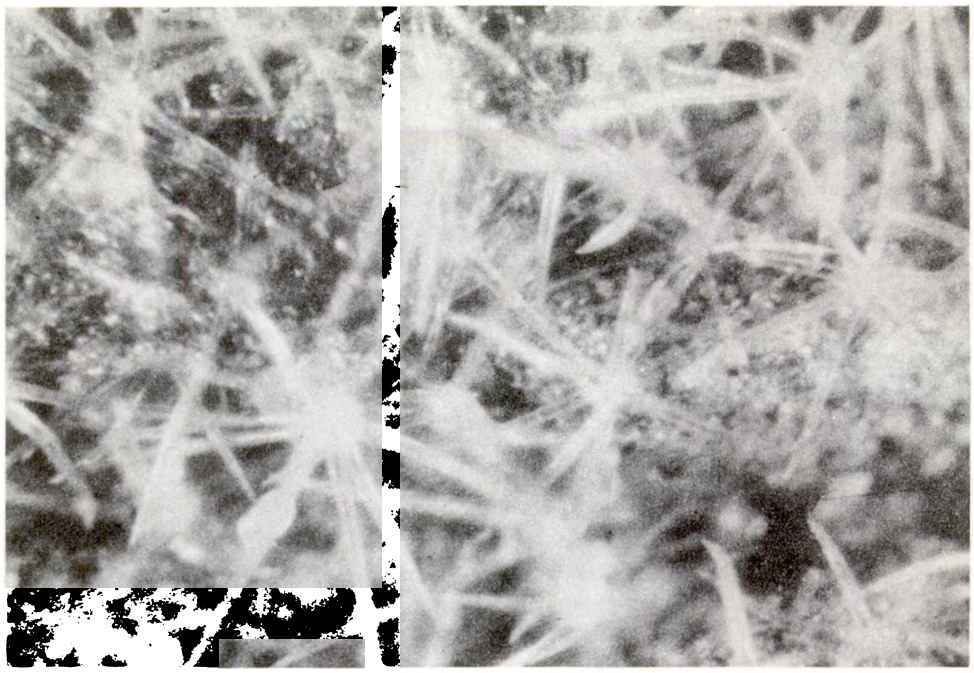
Background soil and plant samples were collected prior to fall-out time at the Project 37.2 master stations.[1] Subsequent to fall-out arrival, three species of forage plants, when

(a)

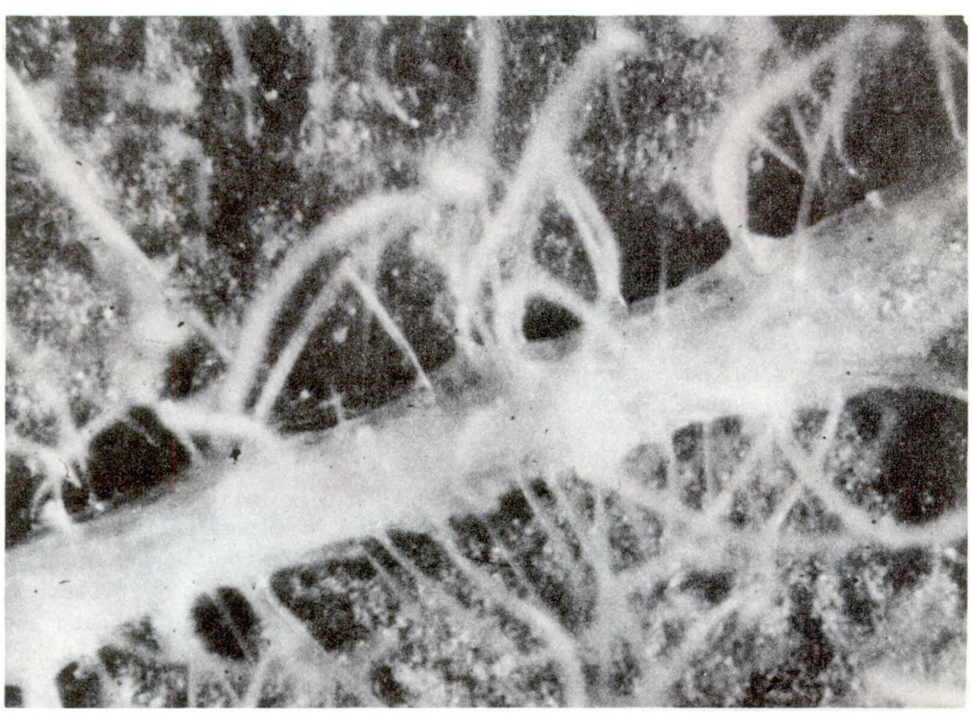


(b)

Fig. 2.3—(a) Leaf surface of bunch grass *(Oryzopsis hymenoides)* showing the sparce barblike hairs, 120×; (b) leaf surface of Great Basin sage *(Artemisia tridentata)* showing the dense matted hairs, 120×.



(a)



(b)

Fig. 2.4—(a) Leaf surface of bush mallow *(Sphaeralcea)* showing the dense stellate hairs, 120×; (b) leaf surface of the wild buckwheat *(Eriogonum)* showing the dense, stiff, unbranched hairs, 120×.

available, were collected from these master stations and from other sampling areas delineated on the basis of postshot monitoring. Levels of surface-soil contamination were determined preshot from three samples of 1 sq ft taken from each sampling site.

Apple II shot soil flats with 2- to 3-month-old clover and wheat plants were placed across the predicted fall-out pattern at preshot-assigned stations approximately 7, 48, and 106 miles from GZ in conjunction with air-sampling stations from Project 37.2. Clover and wheat plants were grown in large soil flats (22 by 22 by 8 in.) and in small soil flats (18 by 18 by 4 in.) filled with Tujunga fine sandy loam soil. One week prior to D-day, one-half of each large flat was harvested in order to expose bare soil surface to fall-out materials. On D−1 day, one large flat each of red clover, turnip, and wheat was placed at each predetermined station location. In addition, two small flats of clover and one small flat of wheat were prelocated at each station. Subsequent to fall-out arrival (beginning about H+6 hr), plant and soil samples were collected from contaminated flats and processed as described in experiments included in Secs. 2.2.2 to 2.2.6.

Except for slight modifications in counting equipment, the methods for radioassay of plants and soils have been previously described.[1,2] Briefly, plant materials were oven-dried at 70°C and ground in a Wiley mill through a 40-mesh screen. Triplicate 0.5-g samples were counted using an end-window Geiger-Mueller (G-M) tube (1.9 mg/cm^2). Observed counts were corrected for instrument geometry using a radium D+E reference standard.

Soil samples were air-dried and sieved through a No. 10 screen. The coarse material (greater than 2 mm in diameter) was discarded since it contained negligible amounts of radioactive material compared to the total activity associated with the collected sample. A 100-g sample of the less than 2-mm fraction was placed in a 4- by 9-in. cardboard tray and counted using a gas-flow beta proportional counter. Observed counts were corrected for self-absorption and instrument geometry. The sieved soil material was separated into 14 sized fractions by further sieving to determine the distribution of radioactive material as a function of particle size.[1]

2.2.2 Determination of Retention of Fall-out Materials on Plant Foliage

A suitable number of leaves were removed at random from indicator plant species at each sampling location; the leaves were then mounted on gummed paper in prepared folders and stored in a botanical press. The prepared folders consisted of a sheet of clear cellulose-acetate gummed paper (7.3 mg/cm^2) and a sheet of botanical drying paper placed inside a Manila folder. Leaf samples were mounted on the sticky side of the gummed paper, with their upper epidermis facing the gum and covered by the drying paper. This procedure formed a permanent mount that could be further processed without disturbing the position of fall-out materials on the leaf surfaces.

The mounting of leaf samples is shown in Figs. 2.5 to 2.7, which show the following steps in the procedure: (1) stripping the protective covering from the cellulose-acetate gummed paper fastened to Manila folders with masking tape; (2) mounting leaf samples on the gummed paper; and (3) covering the mounted samples with botanical drying paper, after which they were placed in a botanical press to dry.

The mounted leaf samples were used to determine total radioactivity and the number and size of fall-out particles per unit area of leaf surface by autoradiographic and optical techniques. Activity per unit area of leaf surface was determined by counting the mounted samples under a 4- by 9-in. gas-flow chamber with a proportional scaler (Fig. 2.8). Observed counts were corrected for instrument geometry using a radium D+E reference standard. Leaf areas were measured with a polar planimeter. Eastman Kodak X-ray film (type K) was exposed to the mounted leaf samples for various time intervals, depending upon the amount of activity retained on the leaves. The number of particles was determined by counting the developed particle images at the different time exposures using a 1-cm^2 grid and a light box. Particle-size ranges were measured with an ocular micrometer using a Leitz binocular microscope. The clear cellulose-acetate paper permitted measurement of the particles without having to remove them from the mounted leaf surfaces.

Comparative studies were made on leaves of the various species of native and domestic plants in order to correlate fall-out-particle retention with leaf characteristics such as leaf hairs, glands, stomata, and other mechanical traps.

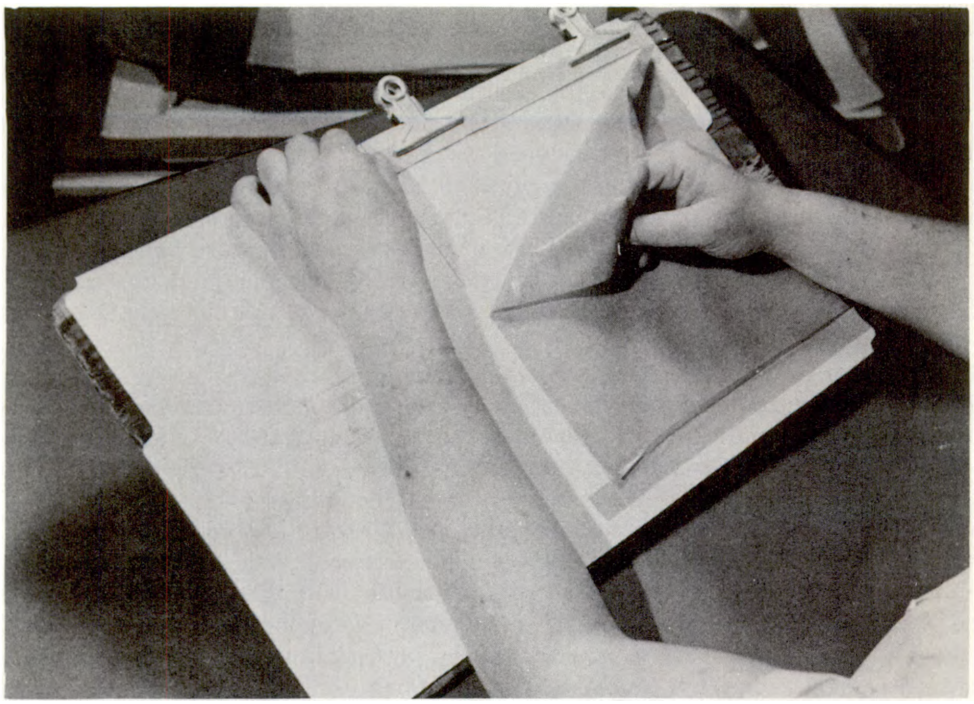


Fig. 2.5—Stripping protective covering from clear-backed cellulose-acetate paper.

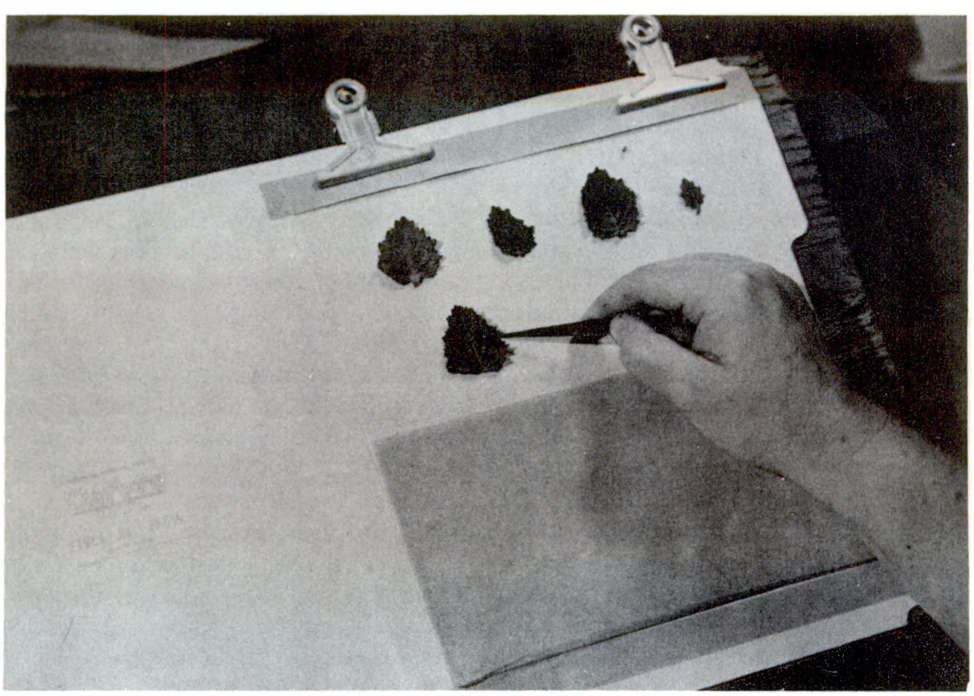


Fig. 2.6—Mounting leaf samples on cellulose-acetate paper.

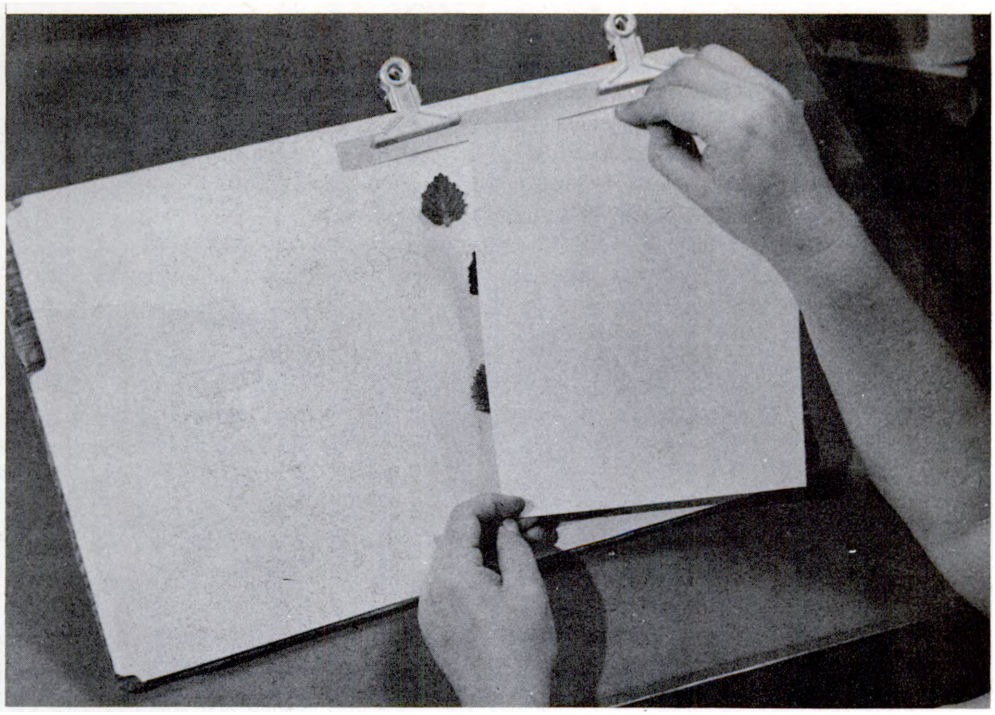


Fig. 2.7—Covering leaf samples with botanical drying paper to form a permanent mount.

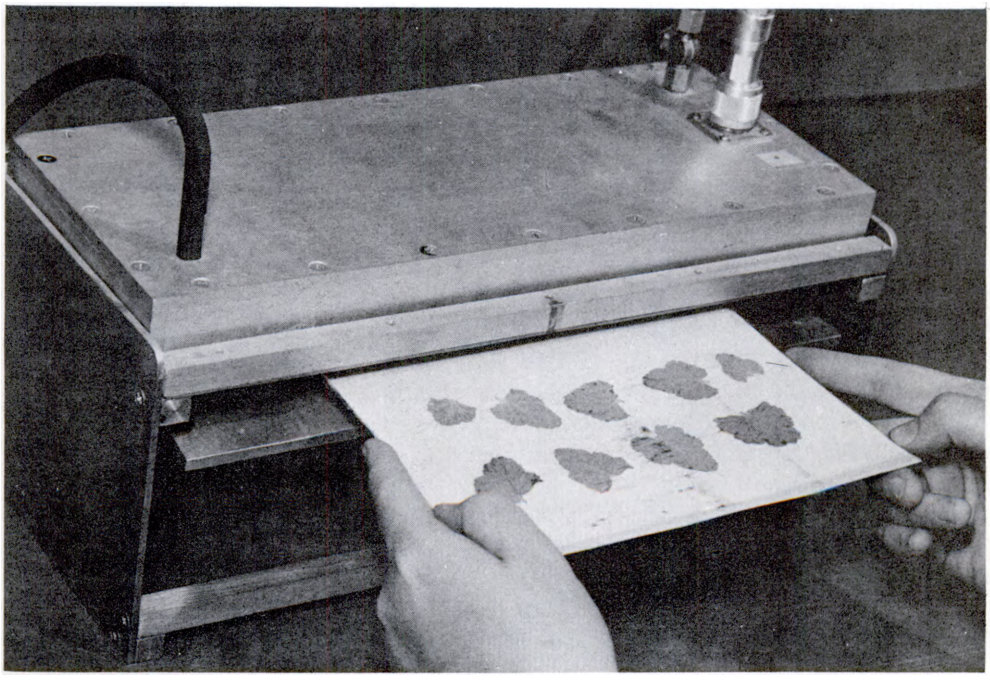


Fig. 2.8—Counting the activity of fall-out particles retained on leaf surfaces using a 4- by 9-in. gas-flow chamber.

2.2.3 Decontamination of Plant Foliage by Washing and Wind Action

Representative samples of fresh plant materials were divided into three replicates and washed with water, 0.1N HCl, and 5 per cent Versene (ethylenediamine tetraacetic acid, or EDTA) solution by dousing the plant materials in these washing media for a total washing time of 10 min. After the samples were rinsed with distilled water, they were air-dried, ground, and radioassayed in order to assess the effectiveness of the various washing media in removing radioactive fall-out materials from plant foliage.

Alfalfa samples were collected from fall-out-contaminated agricultural areas both before and after severe windstorms in order to measure the effectiveness of wind action in either removing fall-out materials from plant foliage or adding fall-out material through redistribution of primary fall-out.

Mechanical damage to the plant foliage as the result of the washing treatments made it impossible to make leaf autoradiograms to show a comparison between the number of particles retained on the washed and unwashed leaves. Therefore, triplicate 0.5-g samples of the dried and ground, washed and unwashed tissues were radioassayed and spread evenly, as near to a single grain layer as possible, between two cellulose-acetate gummed papers. These samples were autoradiographed, and the exposed spots were counted as a means of obtaining a comparison of the number of particles retained on plant foliage before and after the washing treatments.

2.2.4 Determination of Solubility of Fall-out Materials Retained on Plant Foliage

Selected samples of oven-dried plant tissue contaminated with fall-out materials were treated with 0.1N HCl solution to study the solubility characteristics of fall-out materials adhering to plant foliage. The procedure consisted in suspending 0.5-g samples of plant tissue in 10 ml of 0.1N HCl solutions after the samples had been radioassayed. The samples were shaken intermittently for 20 min and then centrifuged for 15 min. The supernatant solution was filtered through a Schleicher and Schull membrane filter, after which the residue was resuspended in 0.1N HCl and the procedure repeated. The filtrate was evaporated in counting cups under infrared lamps and radioassayed. The residue was wet-ashed with concentrated HNO_3 and $HClO_4$, transferred to counting cups in 0.1N HNO_3 solutions, evaporated to dryness, and radioassayed. To determine self-absorption correction factors, 0.5-g samples of the same plant materials from which samples treated with hydrochloric acid solutions had been taken were wet-ashed and radioassayed. Decay correction factors were determined from radioassay of 0.5-g samples of untreated bulk plant tissue.

2.2.5 Determination of Plant Uptake of Radioactive Materials from Fall-out-contaminated Organic Matter Incorporated into Tujunga Soil

Subsequent to fall-out from Apple II shot, one small flat of clover from each contaminated sampling station was covered with heavy wrapping paper and returned to the Environmental Radiation Division greenhouse at UCLA, where the exposed plant material was incorporated into uncontaminated soil in a manner simulating the practice of green manuring of foliage crops. The procedure consisted in inverting the flats of contaminated soil and plant materials onto flats containing a 3-in. layer of uncontaminated Tujunga soil. One-half of the soil in the flats prepared in this manner was seeded to wheat; clover seedlings were transplanted into the remainder of the soil.

Selected samples of plant foliage exposed to fall-out materials were oven-dried, ground through a 40-mesh screen, and incorporated into uncontaminated Tujunga soil, which was then planted with wheat to measure the uptake of fall-out materials from this source of contamination. This process simulated the farm-management practice of returning the plant residues to soil in order to increase its organic-matter content and improve its physical structure.

2.2.6 Determination of Plant Uptake of Radioactive Materials from Tujunga Soil Exposed Directly to Fall-out

To measure the influence of cover crops in reducing the amount of fall-out reaching the soil surfaces, 1-sq ft areas of Tujunga soil (approximately 1 in. deep) were taken from the

surface of small clover flats exposed to fall-out materials after they had been harvested on D-day. Similarly, 1-sq ft areas of soil were taken from the native Nevada soil adjacent to the flats. These samples were compared using radioassay methods discussed in Sec. 2.2.1.

After fall-out had occurred and the exposed plant materials were harvested, all large soil flats were covered with heavy Kraft wrapping paper to reduce cross contamination during transport, and then they were removed from the field to the laboratory at UCLA. The wheat and clover flats were replanted to the same crops to measure differences in uptake of radioactive fall-out materials from bare soil exposed to fall-out and from soil that supported a crop during exposure to fall-out.

2.3 ANIMAL EXPERIMENTS

2.3.1 Collection of Native Animals

The choice of native study animals was determined by their abundance, year-round availability, ease of sampling, and their being of mammalian types. Rodents were collected using metal treadle-type traps baited with rolled oats and placed 50 to 100 ft apart along transects running through contaminated sampling areas. Some larger animals (jack rabbits, kit foxes, and bobcats) were collected along trap lines using single- and double-spring jump traps baited with fox and cat scent. Small jump traps placed on the top of poles were effective in collecting small hawks. Generally, rabbits were collected with .22-caliber rifles, either at night with the aid of a spotlight or in the early morning.

Jack rabbits and some small rodents were obtained prior to fall-out to serve as background controls for samples collected after exposure to fall-out materials. Data were recorded regarding trap yield, species involved, environmental description of sampling area, and routine monitoring. Trapping and collecting of exposed animals usually began 12 hr postshot. Usually by D+1 day the actual midline of fall-out had been defined. When this midline did not coincide with areas already sampled on D-day, the collecting procedure was repeated along the true midline of fall-out at various distances from GZ. Live animals were sacrificed by placing them in a dry-ice (CO_2) chamber. Frozen specimens, individually sealed in plastic bags, were shipped by air freight to the UCLA laboratory for detailed autopsy and radioassay.

2.3.2 Serial Sampling of Native Animals

Serial samples of native animals were taken in an area heavily contaminated with fall-out by Apple I shot, 12 miles from GZ. Samples were collected intermittently through the fifteenth day postshot to study the persistence of radioactive material in a population of animals living in an environment contaminated by radioactive fall-out.

In October and November 1955, a radiological resurvey was made of the area adjacent to NTS. The objectives were (1) to demonstrate the effect of time upon the biological accumulation of fission products from radioactive fall-out and (2) to define more clearly the nature of residual fall-out contamination. By routine beta-gamma monitoring methods, using a Nuclear model 2610A G-M survey meter, it was possible to define a midline of residual fall-out extending from NTS to Grand Junction, Colorado, 417 miles distant. The midline was strongly influenced by the fall-out pattern of Met shot, although several other shots were known to have contributed in much lesser amounts to the residual contamination at some locations. A similar midline of residual fall-out was established from NTS to Steptoe, Nevada, 155 miles distant. This midline was strongly influenced by the fall-out pattern of Apple II shot.

During the resurvey, soil, plant, and animal samples were taken from the midline of residual contamination and from various study areas previously established by the Environmental Radiation Division, Department of Nuclear Medicine and Radiation Biology, UCLA.[2]

2.3.3 Inhalation Studies on Native and Domestic Animals

Live native rodents, collected from uncontaminated areas prior to the scheduled detonations of Met and Apple II shots, were held in hardware cloth cages at predetermined sampling stations 7 miles from GZ. This was done to determine the availability of fall-out materials to the animals primarily through inhalation processes during the time of fall-out.

In addition to the inhalation studies[3] carried out under Project 37.3, Dutch-breed domestic rabbits were placed at predetermined sampling stations across the path of fall-out from Met and Apple II shots at distances of 7, 48, and 106 miles from GZ. At approximately H−4 hr, three animals were placed at each sampling station in exposure boxes (as shown in Fig. 2.2) that were designed to hold the animals in such a way that only their heads were exposed. Control animals were sacrificed at this time. Three sampling stations were set up on the 7-mile arc; six were set up on the 48-mile arc; and three were set up on the 106-mile arc. At fall-out time plus 4 hr, three rabbits on each arc not previously exposed to fall-out were introduced into the study area at the sampling station which had the highest concentration of radioactive contamination. An additional control rabbit was sacrificed at this time, in addition to the three rabbits which were exposed to fall-out materials during the first 4 hr. All remaining animals were exposed for an additional 4 to 6 hr before they were sacrificed.

2.3.4 Laboratory Processing of Animals

In the Environmental Radiation Division laboratory at UCLA, the frozen animal specimens were thawed and autopsied. Small rodents were dipped in hot paraffin and beeswax, which satisfactorily sealed the fur and minimized the possibility of contaminating internal organs with radioactive fall-out material from the pelt. Rabbits were carefully skinned, and their carcasses were thoroughly washed with running tap water before further autopsy was performed. The levels and types of radiation found in different organs often necessitated the use of more than one organ of a given type to provide sufficient amounts of tissue ash for a significant radioassay, i.e., two to four livers, or two to four femurs, etc. Where numerous specimens were available, enough groups of animals were used to ensure the obtaining of a representative sample from each sampling area. In many cases, no more than one specimen of a given species could be obtained from a sampling area, which, of necessity, limited the reliability of the data from that area.

Routine tissue samples consisted of lung, gastrointestinal (GI) tract or caecum, liver, kidney, femur, the muscle associated with the femur, and the thyroid. In selected cases, other organs were also sampled (i.e., mammary tissue, fetus, spleen, and bladder).

The ignition method was chosen as the routine procedure for reducing the tissue samples since, under existing laboratory facilities, this method permitted the handling of larger masses of tissues and of more individual samples in a shorter period of time.[2] Tissues were placed in pyrex beakers, dried in a forced-draft oven at 150°C, and then placed in a muffle furnace. The samples were preheated at 350°C until fuming began; the fumes were ignited, and the final furnace temperature was set at 480°C for 8 to 12 hr for soft tissues. Bones were ignited at 700°C for 2 to 4 hr. A flow of oxygen was supplied to the furnace during this period of time to ensure complete combustion. After cooling, the sample ash was pulverized in the beakers, weighed, transferred to 1-in.-diameter nickel-steel counting cups, and the radioactivity was determined using a mica end-window G-M tube having a thickness of 1.7 mg/cm^2. The observed counts were corrected for instrument geometry using a radium D+E reference standard. Self-absorption corrections were not made unless otherwise noted.

With the exception of thyroid contamination, the radioactivity in tissues had the characteristics of a complex mixture of fission products. Approximate extrapolation for decay was made according to the mixed-fission-product decay function ($t^{-1.2}$). It is recognized that use of the theoretical mixed-fission-product decay function for correcting animal data included in this report may introduce some errors where tissues absorb fission products selectively.[4]

The thyroid was macerated in a stainless-steel counting cup and covered with a sodium thiosulfate solution to fix the iodine present, after which the preparation was gently dried and counted as described previously. Decay corrections for thyroid were made using the decay constant for I^{131}.

2.3.5 Isotopic Identification

During the test series it was possible to identify tentatively more than one radioisotope of iodine in the thyroid of native animals sampled from fall-out-contaminated environments. The resolution of the various isotopes of iodine contributing to the thyroid tissue dose was done by radiation-energy and half-life determinations from samples of thyroid tissue.

Radiostrontium determinations on bone samples were made from three aliquots of bone ash using a fuming nitric acid procedure[5] to precipitate Sr^*NO_3. Total strontium activity, detected with an Anton type G-M tube, was corrected according to the percentage of recovery of both the stable strontium in bone (0.088 per cent of bone ash) and the amount of Sr^{+2} carrier used for the separation. (The percentage of recovery was determined gravimetrically.) The content of Sr^{90} as compared to Sr^{89} was estimated by analysis of the growth curves as Sr^{90} decayed to an equilibrium state with Y^{90} and Sr^{89} decayed to the relatively stable Y^{89}.

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2. R. G. Lindberg et al., Environmental and Biological Fate of Fall-out from Nuclear Detonations in Areas Adjacent to the Nevada Proving Grounds, Project 27.2, Operation Upshot-Knothole Report, WT-812, 1953.
3. G. V. Taplin et al., Evaluation of the Acute Inhalation Hazard from Radioactive Fall-out Materials by Analysis of Results from Field Operations and Controlled Inhalation Studies in the Laboratory, Operation Teapot Report, WT-1172, 1958.
4. K. H. Larson et al., Radioecological Aspects of Nuclear Fall-out, Operation Plumbbob Report, WT-1488, in progress.
5. E. A. Martell, The Chicago Sunshine Method; Absolute Assay of Sr^{90} in Biological Materials, Soils, Waters, and Air Filters, USAEC Report AECU-3262, University of Chicago, Enrico Fermi Institute for Nuclear Studies, May 1956.

Chapter 3

RESULTS

Data pertaining to the uptake of fission products by animals exposed to radioactive fall-out have been reviewed in Chap. 1. To describe further the biological accumulation in terms of the physical characteristics of fall-out at varying distances from GZ, certain inherent limitations were placed on the collection of data. To obtain the best correlation between physical measurements and biological uptake, both kinds of data had to be obtained from the same location during the same time interval. Further, to resolve the effect of fall-out time (distance of the sampling site from GZ), it was desirable to collect samples along the midline of fall-out to ensure the maximum degree of contamination within any one pattern.

Fall-out patterns[1] from each detonation were delineated postshot by Project 37.2. Post-fall-out samples of plants and animals were collected along the midlines of fall-out, in addition to the soil samples used to characterize the fall-out activity and particle-size deposition. Data from biological materials prelocated along the anticipated midline of fall-out were obtained for Met and Apple II detonations and for the position of the sampling sites within the fall-out patterns verified by postshot monitoring.

In some cases, the desired number of animals could not be obtained at the midline location, necessitating supplementation by collection from adjacent areas which were not so highly contaminated. In other cases, the plant and animal species available at each locality varied. However, whenever possible, the same plant and animal species were collected from each location at each distance along the midline of fall-out so that plant and animal data would be comparable with respect to species, distance from GZ, and distance from the midline of fall-out. Pertinent air-borne and particle-size distribution data,[1] as determined by Project 37.2, are also presented.

3.1 PLANT AND SOIL EXPERIMENTS

3.1.1 External Contamination of Plants and Soils by Fall-out Materials

Data for native plants and Nevada soils contaminated by fall-out materials from Tesla, Apple I, Met, and Apple II shots and for domestic plants contaminated by Apple II shot at various distances from GZ are given in Table 3.1. All data were corrected for sample and instrument background, as well as for self-absorption and decay, and were normalized to H + 12 hr. In order to show relations between foliage contamination and the fall-out particle-size ranges thought to be of greatest biological significance, the radioactivity in the particle-size ranges of less than 44 and 5 μ in diameter at each sampling site are included. Particle-size ranges[1] occurring at any sampling site were determined by mechanical analysis of soil samples by Project 37.2. The data in Table 3.1 show a tendency for the radioactivity on the plant foliage to correlate better with the less than 44-μ fall-out particle size than with the total fall-out present.

TABLE 3.1 — BETA ACTIVITY OF PLANT FOLIAGE AND SURFACE SOIL CONTAMINATED BY FALL-OUT MATERIALS FROM TESLA, APPLE I, MET, AND APPLE II SHOTS AT VARIOUS DISTANCES FROM GZ (CORRECTED TO H+12 HR)

Plant species*	Distance from GZ, miles	Distance from midline of fall-out, miles	Surface-soil activity, μc/sq ft			Plant activity (dry basis), mμc/g
			Total	<44 μ	<5 μ	
Tesla Shot						
Atriplex confertifolia†	12	0.1	4334	16.1	11.7	35.8
Yucca brevifolia		1.2	2710	54.5	46.0	13.8
Atriplex confertifolia		1.6	1982	75.9	33.1	16.7
Larrea†	60	0	202	37.8	16.5	83.4
Yucca brevifolia						18.8
Atriplex confertifolia	79	0				8.2
Oryzopsis			183	36.6	21.8	595
Larrea†						82.9
Ceanothus gregii†	96	0	160	40.0	17.7	83.8
Oryzopsis						556
Apple I Shot						
Chrysothamnus	13	1.5	1114	141	54.1	18.0
Artemisia spinescens‡		1.5	1114	141	54.1	395
Artemisia spinescens		2.5	917	95.7	48.5	200
Atriplex confertifolia	40	0.3				251
Ephedra						392
Atriplex confertifolia	40	1.0	303	76.9	44.7	315
Ephedra			303	76.9	44.7	408
Atriplex confertifolia‡	40	1.7	317	110	93.6	261
Ephedra		1.7	317	110	93.6	141
Artemisia spinescens	80	2.0				53.5
Atriplex confertifolia‡			114	28.8	12.7	57.8
Ephedra						70.5
Artemisia tridentata	165	10.0	5.4	3.7	2.1	23.1
Juniperus						20.8
Met Shot						
Larrea§	20	0	5541	274	208	3469
Larrea		3.0	8.7	3.1	0.8	17.3
Larrea§	58	0.2	376	34.2	24.8	892
Lepidium fremontii		0.2	376	34.2	24.8	1923
Ceanothus gregii		0.2	376	34.2	24.8	614
Larrea		1.2	90.1	9.6	8.1	778
Artemisia tridentata§	140	1.5	100	4.8	2.4	265
Alfalfa		2.0	71.5	14.3	5.7	254
Artemisia tridentata		3.0	38.2	7.8	4.4	137
Apple II Shot						
Red clover	7	2.4	74.5	0.63	0.63	16.4
Wheat						32.2
Broad-leaf herb (unidentified)						156
Red clover	7	0.6	2070	3.11	1.65	120
Wheat						121

TABLE 3.1 — (Continued)

Plant species*	Distance from GZ, miles	Distance from midline of fall-out, miles	Surface-soil activity, μc/sq ft			Plant activity (dry basis), mμc/g
			Total	<44 μ	<5 μ	
Apple II Shot (Continued)						
Red clover¶	7	0.9	2475	23	12.9	123
Wheat¶						58.2
Sphaeralcea						55.4
Coleogyne¶						72.7
Wheat	48	3.2	495	63.9	39	349
Wheat						369
Artemisia spinescens						209
Atriplex confertifolia						70
Red clover¶	48	0.8	636	98.7	84.6	324
Wheat¶						381
Artemisia spinescens¶						465
Atriplex confertifolia						125
Red clover	48	2.2	490	78.4	9.12	207
Wheat						157
Artemisia spinescens						180
Atriplex confertifolia						25.3
Red clover	48	5.2	109	18.1	4.78	77.8
Wheat						79.8
Artemisia spinescens						46.2
Atriplex confertifolia						61.4
Red clover	48	8.4	34.0	3.32	1.23	18.6
Wheat						23.4
Artemisia spinescens						30.5
Chrysothamnus						5.98
Red clover	48	11.2	20.0	3.03	2.01	28.9
Wheat						32.1
Artemisia tridentata						18.0
Chrysothamnus						2.33
Mixed native plants¶	106	0	127	25.3	18.0	251
Red clover¶	106	34.0	19.9	14.3	5.14	16.7
Wheat¶						36.1
Chrysothamnus						17.5
Red clover	106	38.0	1.2			16.8
Wheat						11.1
Atriplex confertifolia						9.04
Red clover	106	41.5	1.7			14.2
Wheat						12.8

* For a description of the species, see Table 2.1.
† See Fig. 4.1.
‡ See Fig. 4.2.
§ See Fig. 4.3.
¶ See Fig. 4.4.

The degree of surface-soil contamination by fall-out from Apple II (Table 3.1) at a distance of 48 miles from GZ is representative of the variation found in soil contamination from the midline of fall-out toward the edge of the fall-out path. The width of the fall-out path at any given distance from GZ and the degree of contamination across the path at any given distance from GZ varied considerably, depending in part upon the nature of the shot and, especially, upon the meteorological conditions associated with it. The degree of plant contamination correlated closely to the distribution of the less than 44-μ fraction of fall-out at lateral distances across the path of fall-out. The foliage of different plant species from the same location often retained different levels of activity per unit weight of plant material, presumably because of the discontinuities in fall-out distribution rather than particular leaf characteristics since plants of widely differing leaf morphology can be shown to have similar degrees of particulate contamination.

3.1.2 Retention of Fall-out Materials on Plant Foliage

A typical distribution of fall-out particles retained on plant foliage is shown in Fig. 3.1, which is a print of an autoradiogram exposed for 24 hr to the mounted *Sphaeralcea* leaf samples shown in Fig. 3.2. This sample was collected at a distance of 20 miles from Met shot GZ.

Data given in Tables 3.2 to 3.7 are representative of the number of particles per unit area of leaf surface and the particle-size ranges of fall-out materials retained on leaves of plants contaminated with fall-out from Turk, Ess, Apple I, Met, and Apple II shots at various distances from GZ. The particles retained by leaf surfaces were predominantly less than 44 μ in diameter within the distances from GZ at which samples were collected.

On all shots the number of fall-out particles retained on leaves at any particular location was highly variable; however, the particle-size range distribution was surprisingly uniform. Apple I shot (Table 3.3) had larger sized particles distributed at comparable distances from GZ than the other shots. For Apple I shot, leaf surfaces retained particles ranging from 44 to 125 μ in diameter. There was a noticeable lack of particles less than about 10 μ in diameter from this particular detonation. Plants exposed to Met shot fall-out (Table 3.4) were contaminated with a greater number of active particles per unit leaf area than were leaves exposed to fall-out from the other shots studied. At 20 miles from GZ, the predominant particle size retained on the leaves ranged from 22 to 88 μ in diameter; at 140 miles, the predominant particle size ranged from 5 to 44 μ, reflecting the shift in the particle-size spectrum with increasing distance from GZ.[1]

For red clover exposed to Apple II shot (Table 3.5), there was a noticeable decrease in the number of particles retained per unit leaf area at greater lateral distances from the midline of fall-out. This correlates well with the observation of decreasing activity lateral to the midline shown in Table 3.1. There was a very noticeable predominance of particles retained in the size ranges from 0 to 44 μ in diameter. Native plants retained a few fall-out particles as large as 350 μ in diameter.

Leaf-retention data showed that this procedure had practical application for characterizing the contamination of crops and forage by fall-out particles from a given nuclear detonation. It is apparent from these data that the degree of particulate fall-out contamination to plants is dependent more upon fall-out distribution than plant morphology. There is strong evidence, however, that plant foliage will tend to retain selectively particle-size ranges that are less than 44 μ in diameter, irrespective of the plant species involved or of the total size spectrum of fall-out deposited.

3.1.3 Decontamination of Plant Foliage

Data in Table 3.8 show the effectiveness of distilled water, 0.1N HCl, and 5 per cent Versene (EDTA) solutions in removing radioactive materials from the foliage of several different plant species exposed to fall-out from Met and Apple II shots. Radioactivity was readily removed from smooth, flat, waxy leaf surfaces by each solution. On sticky resinous leaf surfaces, the fall-out materials were quite resistant to removal by washings with distilled water,

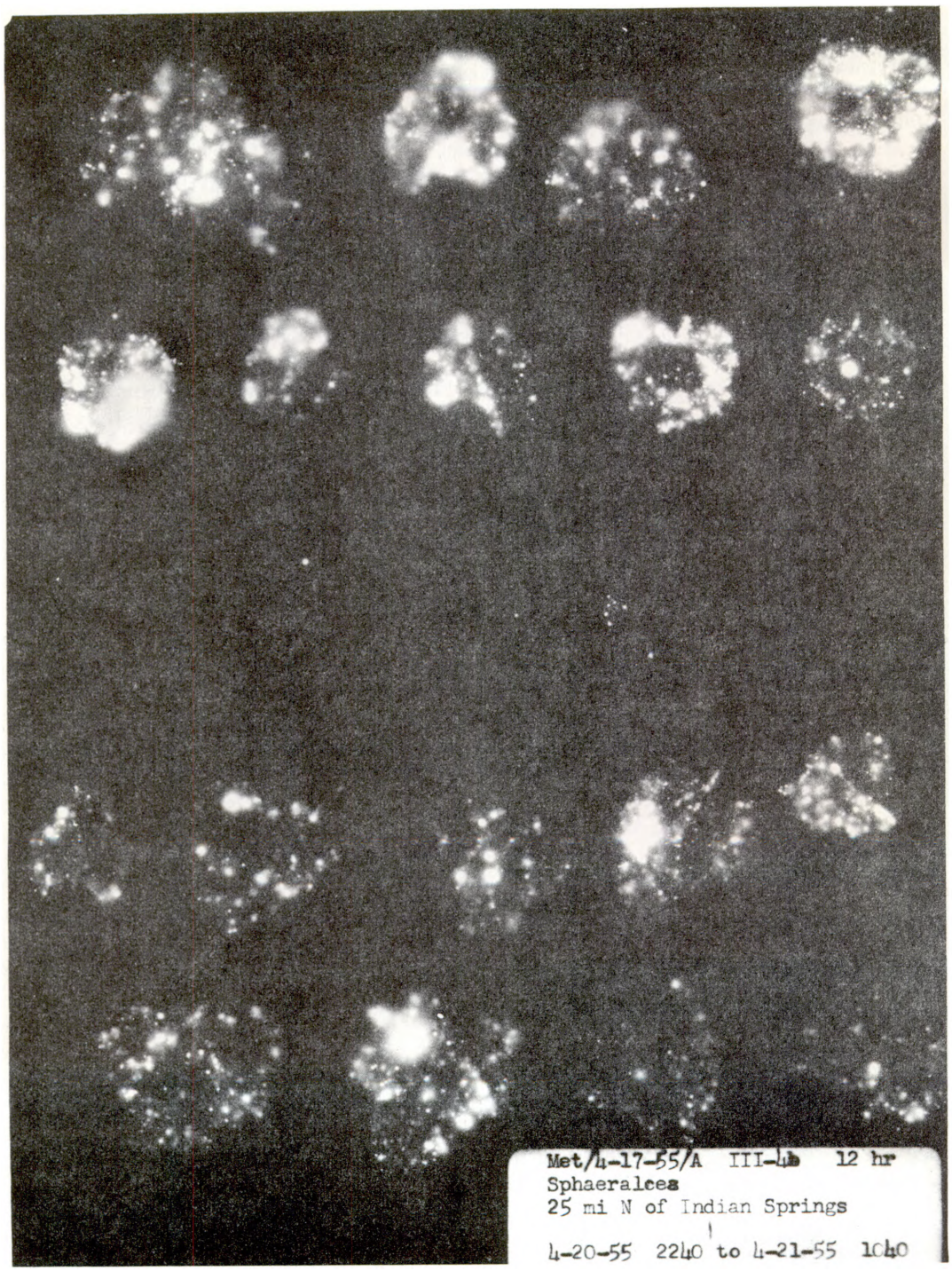


Fig. 3.1 — Print of an autoradiogram exposed for 24 hr to fall-out particles retained on the surface of the mounted *Sphaeralcea* leaves shown in Fig. 3.2.

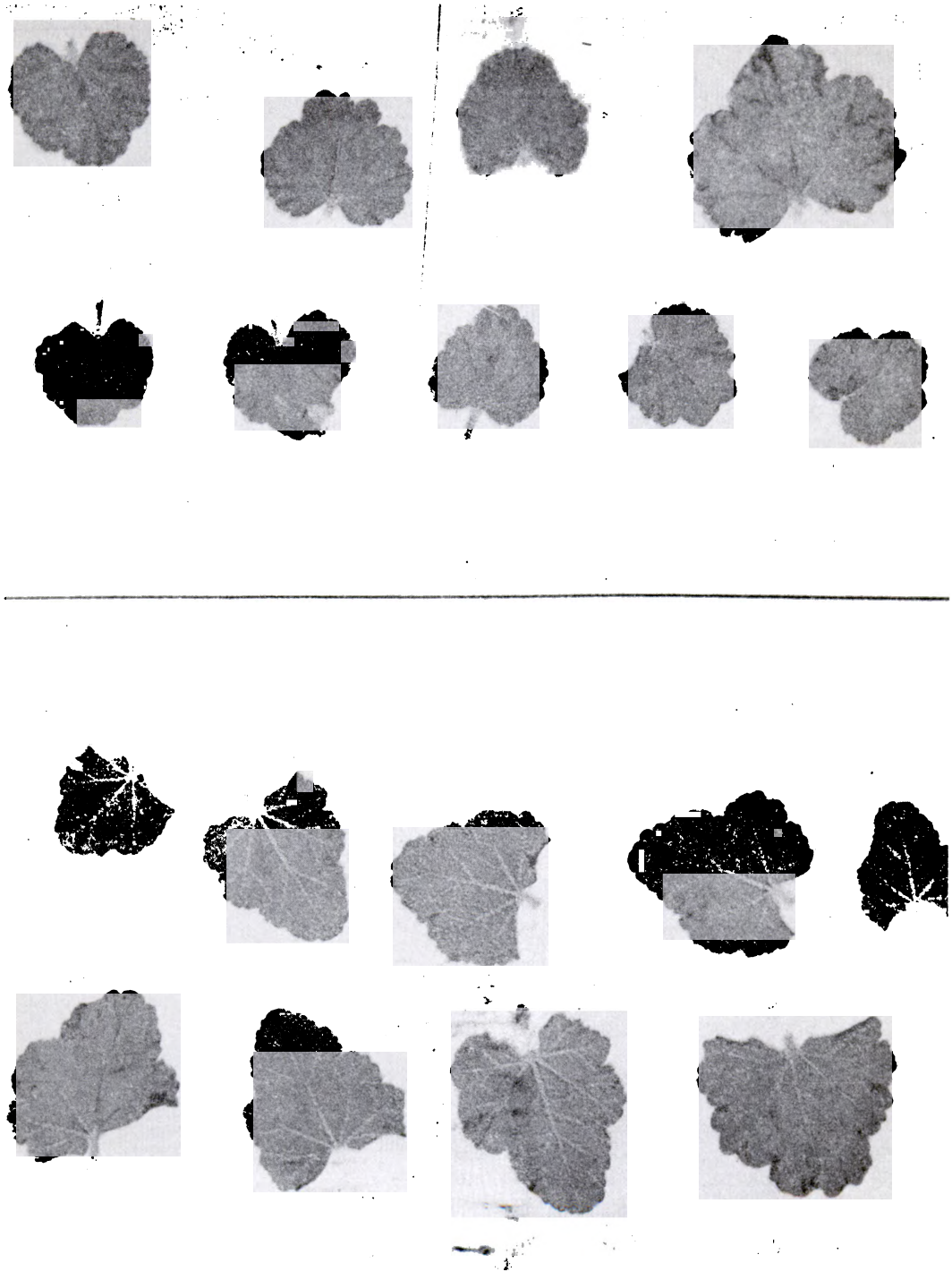


Fig. 3.2—Permanently mounted *Sphaeralcea* leaf samples collected at a distance of 20 miles from Met shot GZ.

TABLE 3.2—SIZE DISTRIBUTION OF FALL-OUT PARTICLES COLLECTED ON LEAVES OF PLANTS* EXPOSED TO FALL-OUT FROM TURK AND ESS SHOTS

	Turk Shot			Ess Shot	
	A. tridentata (matted hairs)†	*Brassica* (rough)†	*Viola* (smooth)†	*Anemone* (scale-like)†	*A. spinescens* (matted hairs)†
Sampling site:					
Distance from GZ, miles	15	15	15	12	12
Lateral distance to midline, miles	5.0	5.0	5.0	0.3	2.0
Total leaf area sampled, cm^2	5.6	102	21.8	28	24
No. of active particles/cm^2	26.3	26.0	172	11.9	22
Particle-size range (percentage of total observed), μ:					
<5	4.0	1.3	2.0	4.0	4.8
5–11	10.8	12.8	15.2	4.0	19.0
11–22	46.6	26.9	36.6	52.0	42.9
22–44	22.7	50.0	35.4	36.0	28.5
44–88	14.6	6.4	8.0	4.0	4.8
88–125	1.3	2.6	4.0	0.0	0.0
125–177	0.0	0.0	0.0	0.0	0.0
177–250	0.0	0.0	0.3	0.0	0.0
>250	0.0	0.0	0.3	0.0	0.0
Total percentage of particles <44 μ	84.1	91.0	89.2	96.0	95.2

* For a description of the species, see Table 2.1.
† Description of leaf surface.

TABLE 3.3—SIZE DISTRIBUTION OF FALL-OUT PARTICLES COLLECTED ON LEAVES OF PLANTS* EXPOSED TO FALL-OUT FROM APPLE I SHOT

	Sphaeralcea (dense stellate hairs)†	*Brassica* (scale-like)†	*Penstemon* (smooth)†	*Eriogonum A* (dense unbranched hairs)†	*Eriogonum B* (dense unbranched hairs)†	*A. tridentata* (matted unbranched hairs)†
Sampling site:						
Distance from GZ, miles	12	12	12	80	80	140
Lateral distance to midline, miles	0.5	1.0	0.5	4.0	4.0	1.5
Total leaf area sampled, cm^2	34	78	96	92	308	80
No. of active particles/cm^2	9.3	8.9	2.8	4.0	2.3	10.4
Particle-size range (percentage of total observed), μ:						
<5	0.0	0.0	0.0	0.0	0.0	0.0
5–11	0.0	0.0	0.0	0.0	0.0	0.0
11–22	9.2	0.0	3.2	0.0	0.0	18.2
22–44	18.1	0.0	22.6	0.0	0.0	66.6
44–88	36.3	21.2	54.8	50.0	44.4	15.2
88–125	9.1	31.8	16.2	21.4	30.6	0.0
125–177	0.0	34.9	0.0	21.4	22.2	0.0
177–250	27.3	10.6	0.0	7.2	2.8	0.0
>250	0.0	1.5	3.2	0.0	0.0	0.0
Total percentage of particles <44 μ	27.3	0	25.8	0	0	84.8

* For a description of the species, see Table 2.1.
† Description of leaf surface.

TABLE 3.4—SIZE DISTRIBUTION OF FALL-OUT PARTICLES COLLECTED ON LEAVES OF PLANTS* EXPOSED TO FALL-OUT FROM MET SHOT

	Penstemon (smooth)†	*Brassica* (scale-like)†	*Sphaeralcea* (dense stellate hairs)†	*Sphaeralcea* (dense stellate hairs)†	*Oryzopsis* (sparse hairs)†	Alfalfa (sparse hairs)†	Alfalfa‡ (sparse hairs)†
Sampling site:							
Distance from GZ, miles	20	20	20	140	140	140	140
Lateral distance to midline, miles	0.0	0.0	0.0	3.0	3.0	2.0	2.0
Total leaf area sampled, cm^2	420.0	110.8	116.8	320.8	48.8	86.2	76.0
No. of active particles/cm^2	12.5	25.6	18.0	23.6	6.8	5.42	5.1
Particle-size range (percentage of total observed), μ:							
<5	1.2	0.0	0.0	0.0	0.0	7.5	3.8
5–11	3.4	17.0	3.2	0.0	5.0	5.0	29.6
11–22	13.5	38.9	9.5	6.9	25.0	37.5	44.4
22–44	32.5	25.4	14.9	20.7	50.0	32.5	22.2
44–88	35.9	16.9	35.1	34.4	15.0	15.0	0.0
88–125	7.9	1.8	21.3	17.2	0.0	0.0	0.0
125–177	2.2	0.0	12.7	17.2	5.0	2.5	0.0
177–250	2.2	0.0	1.1	3.6	0.0	0.0	0.0
>250	1.2	0.0	2.2	0.0	0.0	0.0	0.0
Total percentage of particles <44 μ	50.6	81.3	27.6	27.6	80.0	82.5	100

* For a description of the species, see Table 2.1.

† Description of leaf surface.

‡ After 2 days of wind or dust storms, the alfalfa sample was collected on D+3 days.

TABLE 3.5—SIZE DISTRIBUTION OF FALL-OUT PARTICLES COLLECTED ON LEAVES OF CLOVER PLANTS EXPOSED TO FALL-OUT FROM APPLE II SHOT

	Ladino clover plants from prelocated soil flats exposed to fall-out (rough, with scattered unbranched hairs)							
Sampling site:								
Distance from GZ, miles	7	48	48	48	48	48	106	106
Lateral distance to midline, miles	0.6	0.8	2.2	5.7	8.4	11.2	38	41.5
Total leaf area sampled, cm^2	123.4	275.2	471.4	291.0	255.8	145.2	180.6	128.4
No. of active particles/cm^2	0.75	3.6	1.5	1.1	0.2	0.0	0.0	0.1
Particle-size range (percentage of total observed), μ:								
<5	9.1	19.6	3.7	0.0	0.0	0.0	0.0	0.0
5–11	63.6	23.9	22.2	22.2	37.5	40.0	28.6	0.0
11–22	18.2	23.9	42.6	50.0	37.5	40.0	28.6	0.0
22–44	9.1	21.7	24.1	11.1	12.5	20.0	42.8	100
44–88	0.0	10.9	5.6	11.1	12.5	0.0	0.0	0.0
88–125	0.0	0.0	1.9	5.6	0.0	0.0	0.0	0.0
>125	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total percentage of particles <44 μ	100	89.1	92.6	83.3	87.5	100	100	100

TABLE 3.6—SIZE DISTRIBUTION OF FALL-OUT PARTICLES COLLECTED ON LEAVES OF WHEAT PLANTS EXPOSED TO FALL-OUT FROM APPLE II SHOT

	Wheat plants from prelocated soil flats exposed to fall-out (long slender leaves, with fairly regularly spaced rows of short hairs running parallel to veins)								
Sampling site:									
Distance from GZ, miles	48	48	48	48	48	48	106	106	106
Lateral distance to midline, miles	3.2	0.8	2.2	5.2	8.4	11.2	34	38	41.5
Total leaf area sampled, cm^2	264.4	119.8	116.4	210.0	222.2	121.6	124.8	120.8	63.0
No. of active particles/cm^2	3.4	2.3	1.0	0.2	0.7	0.4	0.1	0.3	0.05
Particle-size range (percentage of total observed), μ:									
<5	0.3	22.5	32.3	12.6	0.0	0.0	0.0	0.0	0.0
5–11	11.8	35.0	38.7	33.0	20.0	28.6	0.0	0.0	50.0
11–22	50.0	22.5	19.4	33.3	60.0	42.8	25.0	28.6	0.0
22–44	26.4	12.5	6.4	8.3	13.4	28.6	75.0	71.4	0.0
44–88	8.8	7.5	3.2	12.5	6.6	0.0	0.0	0.0	50.0
>88	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total percentage of particles <44 μ	88.5	92.5	96.8	87.2	93.4	100	100	100	50

but the hydrochloric acid and Versene solutions removed them more readily. Leaves with dense, hairy surfaces retained more of the fall-out materials than the other types of leaf surfaces treated with the washing solutions.

Data for the number of fall-out particles retained on foliage after the washing treatments indicated, as expected, that large-sized particles are removed more readily than small particles.

A comparison of samples of alfalfa foliage collected on D-day of Met shot from a cultivated field 140 miles from GZ with samples collected from the same location after 2 days of strong winds showed that activity on the plant tissue was reduced 23 per cent, from 0.254 to 0.195 $\mu c/g$. These data are mean values of triplicate samples normalized to H+12 hr. The soil activity at the sample location was 71.5 μc/sq ft at H+12 hr. As indicated in Table 3.4, the associated shift in particle sizes retained on the leaves demonstrates the persistence of particles less than 44 μ in size.

3.1.4 Solubility of Fall-out Materials Retained on Plant Foliage

Data in Table 3.9 show the solubility in 0.1N HCl of fall-out materials retained on foliage from several plant species exposed to Apple I, Met, and Apple II shots at various distances from GZ. Solubility characteristics of air-borne fall-out materials collected in jet impingers and fall-out materials in the less than 5-μ soil particle-size fractions collected from the same sampling locations are also included in Table 3.9. The air-borne and soil particle-size solubility characteristics[1] were determined by Project 37.2.

Data show that the solubility in 0.1N HCl of fall-out materials retained on plant foliage at various distances from GZ varied from 8 to 35 per cent, which was within the same order of magnitude as that observed with the less than 5-μ soil fraction. The solubility in 0.1N HCl of radioactive air-borne materials collected by jet impingers was from two to three times greater than was the active fraction in soil and plant material. The type of plant material had no significant influence on the solubilities of the fall-out materials, nor was there evidence from the plant data that solubility varied with respect to distance from GZ.

3.1.5 Plant Uptake of Radioactive Materials from Fall-out-contaminated Organic Matter Incorporated into Tujunga Soil

Data in Table 3.10 show the availability of radioactive materials to red clover and wheat forage from contaminated green-manure materials incorporated into soil. Detectable amounts

TABLE 3.7—SIZE DISTRIBUTION OF FALL-OUT PARTICLES COLLECTED ON LEAVES OF PLANTS* EXPOSED TO FALL-OUT FROM APPLE II SHOT

	Sphaeralcea (dense stellate hairs)†	*Nyctaginaceae* (smooth)†	*Erodium* (scattered hairs)†	*Oenothera* (dense hairs)†
Sampling site:				
Distance from GZ, miles	7	7	48	48
Lateral distance to midline, miles	0.6	0.9	2.2	2.2
Total leaf area sampled, cm^2	187.8	222.6	82.4	123.0
No. of active particles/cm^2	1.1	0.2	1.6	4.1
Particle-size range (percentage of total observed), μ:				
<44	99.5	100	98.6	96.8
44–88	0.5	0.0	0.7	0.8
88–125	0.0	0.0	0.0	0.0
125–177	0.0	0.0	0.0	0.0
177–250	0.0	0.0	0.0	0.6
250–297	0.0	0.0	0.0	0.0
297–350	0.0	0.0	0.0	0.4
>350	0.0	0.0	0.7	1.4

	Sphaeralcea (dense stellate hairs)†	*A. tridentata* (matted unbranched hairs)†	*Sphaeralcea* (dense stellate hairs)†	*Aquilegia* (scale-like)†	*Helianthus* (hairs on veins and at margins)†
Sampling site:					
Distance from GZ, miles	48	48	106	106	106
Lateral distance to midline, miles	5.2	11.2	34	34	38
Total leaf area sampled, cm^2	116.0	26.2	86.0	332.6	208.6
No. of active particles/cm^2	2.4	1.3	0.5	0.4	0.3
Particle-size range (percentage of total observed), μ:					
<5	96.0	100	97.8	95.4	98.5
44–88	1.4	0.0	0.0	3.0	0.0
88–125	1.8	0.0	0.0	0.8	0.0
125–177	0.0	0.0	0.0	0.8	0.0
177–250	0.0	0.0	0.0	0.0	1.5
250–297	0.0	0.0	2.2	0.0	0.0
297–350	0.4	0.0	0.0	0.0	0.0
>350	0.4	0.0	0.0	0.0	0.0

* For a description of the species, see Table 2.1.
† Description of leaf surface.

of radioactive materials were available to the crop plants up to a period of about 1 year after green-manure organic matter was exposed to fall-out and incorporated into the soil. The amount of radioactivity removed from the contaminated soil by successive croppings was less than 0.1 per cent, particularly for soils contaminated with green manure that had been exposed near GZ. Wheat removed more total activity than red clover, presumably because of higher yields of wheat forage per unit soil area since the activity levels per gram of dry plant tissue were comparable for both plant species.

An interesting observation made during this experiment was the uptake of comparable levels of activity by the crops, irrespective of exposure distance from GZ, and of concentration of fall-out materials in the soil. Although the levels of radioactivity taken up by the crop plants were erratic among the different harvests, there was a tendency for more consistent uptake from the soils contaminated with materials collected at greater distances laterally from the midline of fall-out and at greater distances from GZ. At these locations the radioactive contamination was predominantly in the less than 44-μ particle-size range. Results of

TABLE 3.8—DECONTAMINATION OF PLANT FOLIAGE EXPOSED TO FALL-OUT FROM MET AND APPLE II SHOTS BY WASHING WITH DISTILLED WATER, 0.1N HCl, AND VERSENE (EDTA SOLUTIONS)

Plant species*	Distance at which sample was exposed to fall-out: Miles from GZ	Miles from midline	Total activity removed by washing treatments, %: Dist. H_2O	0.1N HCl	5% Versene	No. of fall-out particles retained on foliage after washing treatments: Un-treated	Dist. H_2O	0.1N HCl	5% Versene
			Met Shot						
Larrea	20	0	48.1	65.7	67.0				
Lepidium fremontii	58	0.2	81.2	89.8	95.1	287	210	124	72
Artemisia tridentata	140	0	36.4	48.8	54.1	372	308	204	150
			Apple II Shot						
Coleogyne	7	0.8	61.8	82.1	72.3	92	38	6	22
Broad-leaf annual	7	2.4	97.8	98.5	98.7	6	2	2	0
Artemisia spinescens	48	2.2	68.5	83.5	83.4	184	60	40	58
Atriplex confertifolia	48	2.2	58.8	81.5	83.1				
Wheat	48	2.2	81.6	90.3	80.6	238	58	28	46
Artemisia tridentata	48	8.4	66.9	80.5	85.6				
Chrysothamnus	48	8.4	62.4	71.3	90.4	38	16	22	4
Atriplex confertifolia	106	38	73.8	74.5	78.9				
Chrysothamnus	106	34	59.5	74.2	89.1				

* For a description of the species, see Table 2.1.

TABLE 3.9—SOLUBILITY IN 0.1N HCl OF FALL-OUT MATERIALS RETAINED ON PLANT FOLIAGE AT VARIOUS DISTANCES FROM GZ

Plant species*	Distance from GZ, miles	Distance from midline of fall-out, miles	Total activity soluble in 0.1N HCl, %: Plant	Air-borne	<5-μ soil
		Apple I Shot			
Artemisia	12	1.5	20.1		27.9
Ephedra	40	1.7	26.6		
Ephedra	80	2.0	14.6		20.1
Juniperus	165	10.0	32.1		14.6
		Met Shot			
Larrea	20	0	26.2	78.2	18.9
Larrea	58	0.2	8.0	67.1	19.4
Alfalfa	140	2.0	14.1	41.0	18.7
		Apple II Shot			
Wheat	7	2.4	19.2	77.4	33.4
Wheat	40	6.0	17.3	67.0	28.1
Wheat	106	23.0	34.7	74.8	23.7

* For a description of the species, see Table 2.1.

TABLE 3.10—UPTAKE OF RADIOACTIVE MATERIALS BY RED CLOVER AND WHEAT FORAGE GROWN ON TUJUNGA SOIL CONTAMINATED WITH CLOVER FORAGE AND SOIL EXPOSED TO FALL-OUT FROM APPLE II SHOT*

Distance at which contaminants were exposed to fall-out		Applied activity (H+12 hr), μc/sq ft	Total activity (mμc) for each harvest from 1 sq ft of contaminated soil† at the indicated time of harvest (days after fall-out)							
Miles from GZ	Miles from midline		D+64	D+107	D+133	D+239	D+302	D+330	D+357	D+386
			Red Clover							
7	0.6E	2162.37	0.029	0.149	NS	NS	0.043	NS	NS	NS
	0.9W	4857.87	0.022	NS	NS	NS	0.049	0.039	NS	0.043
48	0.8E	372.66	0.038	0.011	NS	0.017	0.057	NS	NS	NS
	2.2W	320.42	NS	0.054	NS	NS	NS	NS	0.060	NS
	5.2W	74.46	0.006	0.006	NS	NS	NS	NS	NS	NS
	8.4W	74.50	0.033	0.023	NS	NS	0.047	0.003	0.028	NS
	11.2W	13.75	0.029	0.041	NS	0.016	0.102	0.005	0.066	NS
106	34.0W	12.34	NS	NS	NS	0.017	0.038	NS	NS	NS
	38.0W	2.90	0.031	NS	0.010	0.030	NS	NS	NS	NS
	41.5W	2.95	0.019	0.135	0.029	0.025	0.079	NS	NS	0.007
			Wheat							
7	0.6E	2162.37	0.071		0.049	0.049			NS	
	0.9W	4857.87	0.117		0.081	NS			0.067	
48	0.8E	372.66	0.114	NH	NS	NS	NH	NH	NS	NH
	2.2W	320.42	0.299	NH	NS	NS	NH	NH	NS	NH
	5.2W	74.46	0.184	NH	NS	NS	NH	NH	NS	NH
	8.4W	74.50	0.179	NH	0.079	NS	NH	NH	NS	NH
	11.2W	13.75	0.097	NH	NS	NS	NH	NH	NS	NH
106	34.0W	12.34	NS		NS	0.005			NS	
	38.0W	2.90	0.009		NS	0.009			NS	
	41.5W	2.95	0.347		NS	NS			NS	

*Plant sample and instrument background readings deducted.

†Subsequent harvests at D+424 and D+486 days showed no detectable uptake of radioactive materials.

NS, activity not significantly above normal plant background; NH, no harvest.

this experiment indicated that, up to 1 year after fall-out, detectable amounts of radioactive materials may be available to successive crops grown on soils in which cover crops exposed to fall-out materials have been turned under for green manure. Successive cropping would not appear to be an efficient method for removing radioactive materials from soil that might become contaminated in this manner.

In order to assess the availability to plants of radioactive materials that might be incorporated into soils in the form of contaminated, dry, organic crop residues, native plant materials exposed to fall-out from Met and Apple II shots at various distances from GZ were incorporated into pots of Tujunga soil. Data for uptake of radioactive materials by wheat forage grown on these pots are given in Table 3.11. Results normalized to D+126 days show that radioactive materials were available to the crop; however, with the exception of one treatment, the amount of total activity removed from the soil was less than 0.65 per cent. For Met shot, the activity levels taken up by wheat forage were inversely correlated with the total activity level present in the soil. With one exception, a greater percentage of the total activity added to the soil was removed from pots contaminated with plant residues exposed to Apple II shot than to Met shot. This would indicate a higher degree of availability of radioactive materials from Apple II fall-out materials since the crop yield levels were comparable between the two treatments.

3.1.6 Plant Uptake of Radioactive Materials from Tujunga Soil Exposed Directly to Fall-out

This experiment was designed to observe the influence of red clover and wheat cover crop in reducing the amount of fall-out materials deposited on the soil surface and the subsequent

TABLE 3.11—UPTAKE OF RADIOACTIVE MATERIALS BY WHEAT FORAGE GROWN ON TUJUNGA SOIL CONTAMINATED WITH NATIVE PLANT MATERIAL EXPOSED TO FALL-OUT FROM MET AND APPLE II SHOTS AT VARIOUS DISTANCES FROM GZ*

Kind of native plant material added to soil	Exposure site of contaminated plant material, miles from GZ	Total activity added to 500 g of Tujunga soil, mμc	Total activity removed from contaminated soil by wheat forage crop	
			mμc	%
		Met Shot		
Larrea	20	17.6	0.009	0.05
Lepidium	58	10.0	0.011	0.11
Artemisia	140	3.5	0.023	0.65
		Apple II Shot		
Sphaeralcea	7	1.5	0.037	2.46
Artemisia	48	4.4	0.003	0.06
Atriplex	106	6.3	0.018	0.28

*Data are mean values of three replicates normalized to D+126 days. Each replicate contained 15 g of contaminated plant material mixed with 500 g of Tujunga soil. Control treatments were derived from the same kinds of plant material not contaminated with fall-out. Control values and plant and instrument background readings are deducted.

availability of these radioactive materials to crops grown on these soils. The data given in Table 3.12 show the location of clover flats in the fall-out pattern when the flats were exposed directly to fall-out, the activity levels deposited on the surface of soil with a cover crop and on soil without a cover crop, and the amount of radioactive materials removed from these soils by successive cuttings of red clover, a continuous cropping period of D+486 days. Table 3.13 shows the same data for one crop of wheat harvested 65 days after exposure of soil to fall-out.

Results indicate that the cover crop growing on the soil reduced the fall-out deposited on the soil surface to about one-half of the activity level on the surface of soil exposed without a cover crop at distances of 106 and 48 miles from GZ. Generally, the cuttings of clover removed less than 0.1 per cent of the total activity deposited on the soil surface at each harvest. The higher levels of activity removed by red clover at the D+41- and D+70-day harvests from soil on which clover was growing at the time of exposure to fall-out were attributed mainly to an increased crop yield from this soil. This increase in crop yield was also accompanied by an increased activity per unit weight of dry tissue. No apparent difference in uptake was observed after 95 days, at which time the cutting yields were again comparable for the two soil treatments. No detectable activity above normal plant background was observed in clover cuttings grown after about 400 days following fall-out. A wheat crop grown from a new seeding after fall-out contamination showed no apparent difference in the levels of activity removed from the two soil treatments by comparable crop yields (Table 3.13).

It was not possible to draw conclusions from these data relative to the screening influence of cover crops on the availability of radioactive materials to subsequent croppings of contaminated soil. The levels of activity taken up by the crops were very low (less than twice normal plant background), and they were extremely erratic. On the basis of the degree of soil contamination, there are indications that relatively more uptake occurred from soils exposed at greater distances from GZ and at greater lateral distances from the midline of fall-out. It is apparent from these data that small amounts of radioactive material will be available to successive crop plants from contaminated soil for at least 1 year after exposure to fall-out. No appreciable amount of radioactivity taken up by wheat forage was translocated to the grain. It would appear that levels of contamination from fall-out materials of the type produced from Apple II shot are necessary before crop plants will take up appreciable amounts of radioactivity. Intensive cropping is not an efficient means of removing fall-out contamination from soils.

TABLE 3.12—UPTAKE OF RADIOACTIVE MATERIALS BY RED CLOVER GROWN ON TUJUNGA SOIL EXPOSED DIRECTLY TO FALL-OUT FROM APPLE II SHOT*

Distance at which soil was exposed to fall-out		Soil activity (H+12 hr), μc/sq ft	Total activity (mμc) for each harvest from 1 sq ft of contaminated soil† at the indicated time of harvest (days after fall-out)								
Miles from GZ	Miles from midline		D+41	D+70	D+95	D+107	D+133	D+231	D+302	D+330	D+357
			Clover Growing on Soil at Time of Fall-out								
7	2.4E	27.3	0.044	0.072	NS	NS	NS	NS	NS	NS	NS
	0.6E	1053.0	0.096	0.174	0.007	NS	NS	NS	0.124	0.009	NS
	0.9W	3344.0	0.119	0.089	NS	NS	NS	NS	0.081	NS	0.012
48	3.2E	201.0	0.233	0.284	0.113	0.033	0.066			0.043	NS
	0.8E	504.0	0.222	0.183	0.024	NS	0.091	NS	0.036	NS	NS
	2.2E	217.0	0.068	0.150	NS	NS	NS	NS	NS	NS	NS
	5.2E		0.193	0.203	0.030	0.022	0.084	NS	NS	NS	NS
	8.4W	32.0	0.046	0.104	0.176	0.126	NS	NS	NS	0.050	NS
	11.2W	9.0	0.067	0.051	0.157	0.157	0.023	NS	NS	0.026	NS
106	34.0W	8.2	0.087	0.068	0.113	NS	NS	NS	NS	NS	NS
	38.0W	1.7	NS	NS	NS	NS	NS	NS	NS	NS	NS
	41.5W		0.023	NS	NS	NS	NS	NS	NS	NS	NS
			Clover Cutting Harvested Just Before Exposure to Fall-out								
7	2.4E	74.5	0.055	0.042	0.095	NS	0.023	NS	NS	NS	NS
	0.6E	2070.1	0.008	0.038	0.088	0.034	NS	NS	NS	0.017	NS
	0.9W	2475.5	0.005	0.013	0.133	0.073	NS	NS	NS	NS	NS
48	3.2E	495.9	0.030	0.036	0.009	0.063	0.081	NS	0.022	0.047	NS
	0.8E	646.6	0.063	0.110	0.039	0.048	0.103	NS	0.022	0.032	NS
	2.2W	490.1	0.090	0.058	0.110	0.022	NS	NS	NS	NS	NS
	5.2W	108.7	0.026	0.077	0.048	0.043	0.026	NS	NS	NS	NS
	8.4W	34.0	0.032	0.085	0.085	0.043	0.061	NS	NS	0.009	NS
	11.2W	20.0	0.027	0.054	0.054	0.031	NS	NS	NS	0.035	NS
106	34.0W	19.9	NS	NS	0.044	NS	NS	NS	NS	NS	NS
	38.0W	1.2	0.004	NS	0.050	NS	NS	NS	NS	NS	NS
	41.5W	1.7	0.003	NS	0.012		NS	NS	NS	NS	NS

*Plant sample and instrument background readings deducted.

†Traces of activity were detected in D+386-day harvest; no detectable activity in D+424 or D+486 days.

NS, activity not significantly above normal plant background.

3.2 ANIMAL SAMPLING AND EXPERIMENTS

3.2.1 Tissue-reference Values (Pre-Teapot)

Table 3.14 is a summary of the levels of beta activity in tissues of native animals sampled from a number of areas adjacent to NTS approximately 1 month prior to the initiation of the test detonations. The values reported will be considered normal animal background prior to Operation Teapot. Data obtained from samples collected during the test series were required to reflect levels of twice these tissue-reference values in order to be considered significant or attributable specifically to Operation Teapot.

3.2.2 Contamination of Native Animals Exposed to Fall-out Materials

Tables 3.15 to 3.19, inclusive, summarize the occurrence of fission products in tissues of animals sampled from within specific fall-out patterns as a function of the position of the sampling site within the fall-out pattern. Activities in all tissues except thyroid were corrected for radioactive decay to the time of sacrifice using the mixed-fission-product decay

TABLE 3.13—UPTAKE OF RADIOACTIVE MATERIALS BY WHEAT GROWN ON TUJUNGA SOIL EXPOSED DIRECTLY TO FALL-OUT FROM APPLE II SHOT*

Distance at which soil was exposed to fall-out		Soil activity (H+12 hr), μc/sq ft	Crop activity harvested at D+35 days from 1 sq ft of soil, mμc
Miles from GZ	Miles from midline		
Wheat Crop Harvested Just Before Exposure to Fall-out			
7	2.4E	57.4	0.426
	0.6E	2070.1	0.293
	0.9W	2475.5	0.179
48	3.2E	495.9	0.239
	0.8E	646.6	0.318
	2.2W	490.1	0.072
	5.2W	108.7	0.198
	8.4W	34.0	0.177
	11.2W	20.0	0.013
106	34.0W	19.9	0.321
	38.0W	1.2	0.182
	41.5W	1.7	0.138
Wheat Crop Growing on Soil When Exposed to Fall-out			
7	2.4E	15.0	0.560
	0.6E	1487.0	0.030
	0.9W	2123.0	0.533
48	3.2E	201.0	0.221
	0.8E	251.0	0.027
	2.2W	274.0	0.085
	5.2W	50.1	0.542
	8.4W	51.0	0.294
	11.2W	9.0	0.025
106	34.0W	8.2	0.014
	38.0W	6.4	0.367
	41.5W		0.177

* Plant sample and instrument background readings deducted.

function ($t^{-1.2}$). Thyroid activity was corrected for radioactive decay using the I^{131} decay constant. In the case of selective absorption of certain fission products by different tissues, some error may be introduced by using the mixed-fission-product decay function. However, comparisons of the observed radioactive decay of the lung, muscle, femur, and GI tract sampled during a 2- to 4-week period following fall-out showed only slight deviation from the mixed-fission-product decay function. During shorter time intervals after fall-out, greater deviations may occur; however, limited data indicate that the error introduced would be less than a factor of 2. The radioactive decay of liver and kidney, however, was more rapid as it approached a $t^{-2.0}$ decay slope. The observed decays were too variable to permit the selection of a better decay correction than the beta decay function of $t^{-1.2}$. The values reported for liver and kidney are probably low by a factor of 2 to 4.

In reading this report, special care should be taken to note the relative time and location from which each sample was obtained (Fig. 3.3). As an example, only those animals sampled a comparable distance from the midline of fall-out after similar exposure times to the fall-out-contaminated environment can be used to examine the effect of the distance of the sampling site from GZ, whereas data presented for a given species serially sampled from the same location over a period of time must be used to evaluate the biological persistence of radioactive fall-out.

Of special interest in Tesla samples (Table 3.15) is the relatively high thyroid activity in the cottontail rabbit sampled to 65 miles from GZ, as compared to the thyroid burden of jack

TABLE 3.14—AVERAGE BETA ACTIVITY IN TISSUES OF ANIMALS* SAMPLED FROM AREAS ADJACENT TO NTS IMMEDIATELY PRIOR TO OPERATION TEAPOT

Location (see Fig. 3.3)	Distance from Yucca Flat, miles	Date sampled (1955)	Fresh tissue, d/m/g					
			Lung	Liver	Kidney	Muscle	Bone	Caecum
		Jack Rabbits						
1	40SW	Feb. 4	2.38	2.27	2.80	3.30	4.80	12.5
		Feb. 4	2.68	2.54	3.16	2.68	3.68	11.1
2	17NNE	Feb. 7	2.26	2.27	3.25	2.56	6.59	16.0
3	19NNE	Feb. 7	2.44	2.92	3.45	2.81	5.69	
3	19NNE	Feb. 7	2.10	2.47	2.88	3.10	5.46	17.3
4	19NNE	Feb. 7	2.14	1.77	3.08	2.59	5.11	14.5
5	17NE	Feb. 7	2.30	2.71	3.06	2.66	1.46	
5	17NE	Feb. 7	2.70	2.05	2.72	2.87	5.38	12.3
6	61NE	Feb. 9	3.78	2.96	5.94	2.43	4.19	8.29
6	61NE	Feb. 9	2.61	2.50	2.69	3.08	7.49	11.0
7	48N	Feb. 7	2.24	2.38	3.84	2.56	6.51	8.52
8	17N	Feb. 15	2.61	3.38	2.95	2.15	9.39	14.7
9	17N	Feb. 17	2.67	3.30	2.54	2.60	6.98	38.2
10	44NE	Feb. 14	2.55	2.32	2.53	3.02	1.70	9.20
10	44NE	Feb. 14	2.00	2.38	2.56	2.65	2.15	12.0
10	44NE	Feb. 14	2.60	2.56	2.31	3.54	1.98	11.1
10	44NE	Feb. 14	1.93	1.84	2.66	3.03	3.32	9.87
10	44NE	Feb. 14	2.0	2.4	2.07	2.36	3.19	11.9
11	NTS	Feb. 28	2.35	2.24	2.32	2.28	1.42	15.7
12	45SE	Feb. 28	2.26	3.40	3.78	2.32	5.78	25.9
26 miles west of Ely, Nev.	140N	Feb. 8	2.26	3.19	2.70	2.07	4.33	13.0
Average d/m/g			2.42	2.56	3.01	2.70	4.60	14.4
mμc/g			0.001	0.001	0.001	0.001	0.002	0.007
		Cottontail Rabbits						
13	45SE	Feb. 28	3.81	4.22	3.77	2.92	3.98	53.8
		Feb. 14	3.36	3.39	5.56	3.37	11.92	11.1
		Kit Fox						
14	40SW	Feb. 4	1.78	1.25	2.26	3.35	1.16	6.62†
		Feb. 4	2.13	1.74	2.15	3.27	1.95	3.08†
15	NTS	Feb. 24	1.53	1.33	2.27	2.93	0.86	2.76†
16	31S	Feb. 24	1.78	1.99	2.58	2.78	2.20	4.57†
15	NTS	Feb. 28	1.55	1.56	1.54	3.0		4.80†
Average			1.75	1.57	2.16	3.06	1.54	4.37†
		Bobcat						
17	45SE	Feb. 4	1.25	1.81	1.82	2.75		2.42†
		Gray Fox						
18	45SE	Mar. 6	1.63	2.19	2.17	2.87	2.54	4.64†
19	45SE	Mar. 10	1.74	2.39	2.33	4.47	2.74	4.46†

* Tissue-reference values for this period are also available for *Peromyscus*, *Perognathus*, *Dipodomys*, *Citellus*, and *Neotoma*. Data suggest that these values are similar to those given for jack rabbits, therefore they will so be considered in this report.

† These values are from tissue samples of the stomach.

TABLE 3.15—AVERAGE BETA ACTIVITY IN TISSUES OF NATIVE ANIMALS SAMPLED ALONG THE MIDLINE OF FALL-OUT FROM TESLA SHOT AT VARIOUS DISTANCES FROM GZ

Animal species*	No. of animals	Distance from GZ, miles	Sampling time (days after shot)	Average activity extrapolated to time of sampling (wet-tissue basis),† mμc/g						
				Lung	Liver	Kidney	Muscle	Femur	Thyroid	GI
D. microps	2	8.5	2	0.014	0.103	0.043	0.030	0.026	23.7	1.23
D. merriami	35	65	25	0.017	0.016	0.015	0.013	0.019	9.15	0.239
D. deserti	5	65	25	0.008	0.009	0.008	0.007	0.021	16.4	0.310
Citellus	1	65	25	0.006	0.007	0.004	0.009	0.013	2.71	0.593
D. merriami	41	93	25	0.005	0.004	0.005	0.003	0.011	4.19	0.058
D. microps	27	93	25	0.006	0.011	0.007	0.003	0.013	12.0	0.063
P. formosus	4	93	25	0.008	0.009	0.012	0.008	0.026	13.8	0.045
L. californicus	1	8.5	1	0.078	0.090	0.087	0.104	0.054	19.2	1.19
L. californicus	3	65	25	0.011	0.006	0.009	0.004	0.019	9.52	0.368
Sylvilagus	1	65	D-day	1.07	0.340	0.414	0.494	0.222	110	51.3
	1	65	25	0.031	0.026	0.015	0.006	0.043	33.4	0.470

* Genera: *D* = *Dipodomys*, *P* = *Perognathus*, and *L* = *Lepus* (see Sec. 2.1.3).
† Tissue-reference values deducted (Table 3.14).

TABLE 3.16—AVERAGE BETA ACTIVITY IN TISSUES OF NATIVE ANIMALS SAMPLED ALONG THE MIDLINE OF FALL-OUT FROM APPLE I SHOT AT VARIOUS DISTANCES FROM GZ

Animal species*	No. of animals	Distance, miles		Sampling time (hours after shot)	Average activity extrapolated to time of sampling (wet-tissue basis),† mμc/g						
		GZ	Midline		Lung	Liver	Kidney	Muscle	Femur	Thyroid	GI
D. merriami[1]	1	12	1.5	20	0.26	1.72	1.02	0.13	0.13	1.36	82.27
D. microps	1		1.5	20	0.05	0.74	0.22	0.14	0.17	2.86	19.21
L. californicus[2]	2		2.0	14	0.19	0.12	0.21	0.06	0.42	0.88	27.88
L. californicus	1		0.5	15	0.25	0.12	0.15	0.08	0.21	2.03	7.52
D. microps	3	40	1.0	76	0.05	0.22	0.12	0.05	0.15	9.65	1.45
P. formosus[3]	1		1.0	76	0.32	0.21	0.17	0.16	0.63	4.87	3.46
L. californicus	1	63	0.5	54	0.07	0.01	0.13	0.06	0.01	19.4	15.55
L. californicus	5	80	0.5	60	0.10	0.97	0.38	0.32	0.54	12.65	14.01
L. californicus	2		0.5	84	0.06	0.98	0.36	0.06	0.10	7.18	4.34
L. californicus	5		2.0	276	0.02	0.02	0.02	0.01	0.06	5.82	0.60
S. auduboni[4]	2		2.0	60	0.13	0.07	0.15	0.05	0.05	13.9	3.73
D. microps	1		0.5	96	0.03	0.41	0.14	0.04	0.20	11.8	2.47
P. formosus	1		0.5	96	0.03	0.04	0.07	0.03	0.04	16.1	0.43
L. californicus	1	92	2.0	72	0.08	0.03	0.10	0.04	1.42	0.90	0.26
P. maniculatus[5]	9	140	5.0	42	0.17	0.26	0.14	0.23	0.19	5.51	2.42
P. maniculatus	6		5.0	54	0.05	0.09	0.04	0.03	0.15	3.00	0.36
L. californicus	4		0.5	43	0.13	0.18	0.07	0.12	0.24	3.25	7.13
L. californicus	3		0.5	280	0.01	<0.01	<0.01	<0.01	0.01	1.21	0.31
S. auduboni	1		0.5	42	0.81	0.21	0.11	0.03	0.09	7.31	2.32
L. californicus	6	165	10.0	43	0.04	0.18	0.14	0.07	0.09	2.64	2.54
L. californicus	4		10.0	284	<0.01	<0.01	<0.01	<0.01	0.02	4.48	0.15

* Genera: 1. *Dipodomys*, 2. *Lepus*, 3. *Perognathus*, 4. *Sylvilagus*, and 5. *Peromyscus* (see Sec. 2.1.3).
† Tissue-reference values deducted (Table 3.14).

TABLE 3.17—AVERAGE BETA ACTIVITY IN TISSUES OF NATIVE ANIMALS SAMPLED ALONG THE MIDLINE OF FALL-OUT FROM MET SHOT AT VARIOUS DISTANCES FROM GZ

Animal species*	No. of animals	Distance, miles		Sampling time (hours after shot)	Average activity extrapolated to time of sampling (wet-tissue basis),† mμc/g						
		GZ	Midline		Lung	Liver	Kidney	Muscle	Femur	Thyroid	GI
D. merriami[1]	5	20	0.0	54	1.29	1.54	1.55	0.43	2.84	94.8	38.9
N. lepida[2]	9			54	5.75	2.08	2.57	1.07	17.25	125.3	67.2
P. formosus[3]	18			54	1.23	2.81	3.23	2.56	3.72	33.5	132.4
O. torridus[4]	1			54	2.33	1.60	1.29	1.80	21.04	105.9	47.0
D. merriami	23	58	0.2	36	0.55	0.91	9.01	0.49	0.85	203.8	35.3
D. deserti	2			36	0.36	0.55	0.71	0.30	1.06	228.7	32.9
D. formosus	2			44	1.05	1.40	1.33	0.66	1.03	98.8	48.6
O. torridus	3			44	1.08	1.51	1.00	0.63	4.88	132.3	66.3
C. leucurus[5]	1			36	0.75	0.56	0.55	1.12	6.81	222.3	64.7
L. californicus[6]	4	140	3.0	34	0.55	0.44	0.87	0.02	0.88	97.2	26.8
L. californicus	1		1.5	60	0.53	0.53	0.60	0.02	0.72	81.0	66.3
D. microps	8		1.3	36	0.07	0.19	0.16	0.12	0.23	22.1	6.9
D. microps	1		1.3	72	0.02	0.07	0.09	0.03	0.19	10.2	1.7
D. ordii	1		1.3	72	0.08	0.07	0.15	0.06	1.05	1.37	0.6
P. parvus	9		1.3	36	0.21	0.33	0.19	0.88	0.70	28.0	9.4
P. parvus	1		1.3	72	0.04	0.23	0.05	0.06	0.03	21.6	7.3
R. megalutus[7]	4		1.3	36	0.28	0.91	0.65	2.29	1.59	20.8	32.9
R. megalutus	2		1.3	44	0.18	0.71	0.63	0.46	1.26	55.5	16.9
R. megalutus	10		1.3	72	0.08	0.31	0.23	0.19	0.88	46.9	8.3
P. maniculatus[8]	5		1.3	36	0.44	0.69	0.59	0.28	2.75	92.5	19.4
P. maniculatus	3		1.3	44	0.21	1.10	0.73	0.40	5.56	86.4	0.2
P. maniculatus	6		1.3	72	0.07	0.19	0.14	0.18	1.38	33.1	5.2
M. megacephalus[9]	3		1.3	72	0.08	0.14	0.07	0.25	1.01	12.8	4.4

*Genera: 1. *Dipodomys*, 2. *Neotoma*, 3. *Perognathus*, 4. *Onychomys*, 5. *Citellus*, 6. *Lepus*, 7. *Reithrodontomys*, 8. *Peromyscus*, and 9. *Microdipodops* (see Sec. 2.1.3).

† Tissue-reference values deducted (Table 3.14).

TABLE 3.18—AVERAGE BETA ACTIVITY IN TISSUES OF NATIVE ANIMALS SAMPLED ALONG THE MIDLINE OF FALL-OUT FROM APPLE II SHOT AT VARIOUS DISTANCES FROM GZ

Animal species*	No. of animals	Distances, miles		Sampling time (hours after shot)	Average activity extrapolated to time of sampling (wet-tissue basis),† mμc/g						
		GZ	Midline		Lung	Liver	Kidney	Muscle	Femur	Thyroid	GI
L. californicus	1	29	4	42	0.67	0.15	0.79	0.05	0.24	9.0	7.19
L. californicus	1	36	2	40	0.17	0.10	0.14	0.07	0.23	99.2	3.65
L. californicus	1	36	2	46	0.16	0.31	0.14	0.06	0.23	37.9	6.38
L. californicus	1	36	2	46	0.06	0.11	0.11	0.05	0.36	18.1	1.12
L. californicus	1	36	1	40	0.20	0.38	0.45	0.27	2.30	44.7	14.9
L. californicus	1	36	0	41	0.07	0.08	0.10	0.03	0.47	13.5	5.94
C. latrans	1	36	12	38	0.05	0.04	0.03	0.09	0.01	17.5	0.22
L. californicus	1	45	1	42	0.08	0.34	0.34	0.14	0.39	98.4	1536
L. californicus	1	48	1.2	42	0.11	0.12	0.14	0.17	0.23	61.7	10.1
L. californicus	1	48	0.2	42	0.34	0.28	0.45	0.94	3.67	191	26.5
L. californicus	1	48	5.8	41	0.11	0.13	0.16	0.08	<0.27	389	92.7
L. californicus	1	48	5.8	40	0.31	0.83	0.44	0.10	0.69	57.2	19.3
L. californicus	1	48	6.8	43	0.10	0.29	0.21	0.08	0.29	48.2	7.53
D. microps	13	48	0.8	56	0.02	0.03	0.02	0.02	0.29	40.3	7.47
P. parvus	1	100	0	51	0.19	0.28	0.46	0.48	0.39	123	17.8
P. formosus	2	100	0	51	0.31	0.57	0.17	0.72	13.9	349	28.1

* Genera: *L* = *Lepus*, *C* = *Canis coyote*, *D* = *Dipodomys*, and *P* = *Perognathus* (see Sec. 2.1.3).

† Tissue-reference values deducted (Table 3.14).

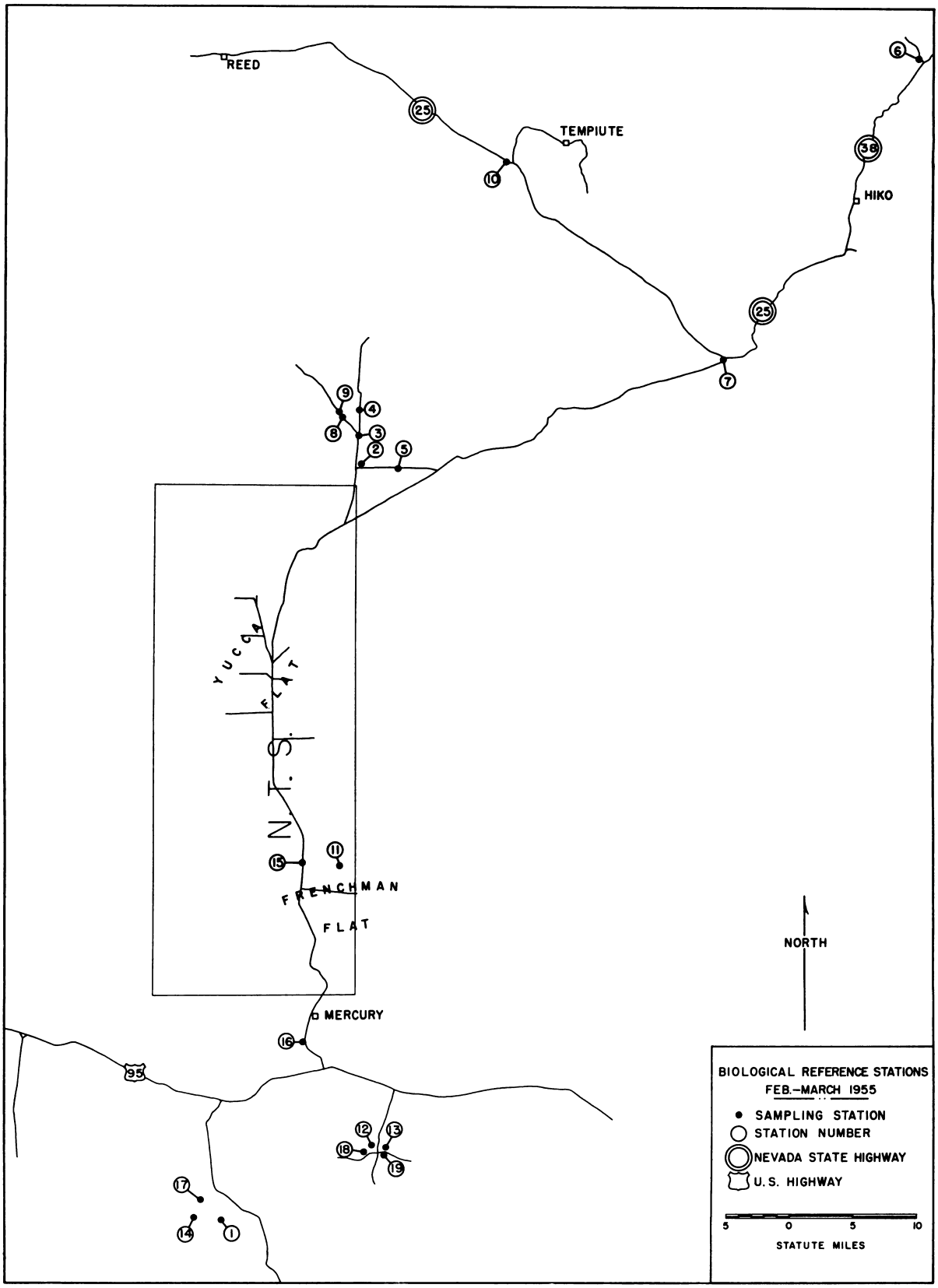


Fig. 3.3—Biological reference stations, February-March 1955.

TABLE 3.19—AVERAGE BETA ACTIVITY IN TISSUES OF NATIVE ANIMALS SAMPLED ALONG THE MIDLINE OF FALL-OUT FROM SEVERAL SHOTS AT VARIOUS DISTANCES FROM GZ

Animal species*	No. of animals	Distance, miles		Sampling time (hours after shot)	Average activity extrapolated to time of sampling (wet-tissue basis),† mμc/g						
		GZ	Midline		Lung	Liver	Kidney	Muscle	Femur	Thyroid	GI
Turk Shot											
L. californicus	1	11	0	15	1.10	0.25	0.58	0.52	0.50	0.88	443
Sylvilagus	1	11	0	230	0.74	1.97	1.36	0.15	1.44	3279	34.3
Bee Shot											
P. longimembris	2	100	0	33	0.01	0.08	0.01	0.02	0.07	8.08	0.82
P. formosus	1	100	0	33	0.88	0.96	1.20	1.23	1.30	7.99	19.7
Ess Shot											
D. merriami	1	15	0	20	2.07	1.98	1.13	0.92	4.97	150	73.1
D. merriami	1	30	0	24	4.09	2.35	3.06	3.52	34.0	141	143
L. californicus	1	30	2	10	1.87	1.06	1.87	0.76	1.75	30.3	103
L. californicus	1	15	1.8	12	0.32	0.41	0.52	0.22	0.62	86.5	32.6
L. californicus	1	15	1.9	11	1.05	0.80	1.02	0.47	1.07	20.4	89.1
L. californicus	1	15	8	7	1.70	1.69	1.03	0.40	0.95	54.9	18.4
L. californicus	1	15	9.5	6	0.35	0.08	0.16	0.12	0.31	1.04	2.53
Post Shot											
D. merriami	1	45	0	30	0	0.06	0.02	0.09	0.07	0.14	1.91
D. deserti	9	45	0	30	0.01	0.04	0.02	0.02	0.03	18.0	0.71
N. lepida	3	45	0	25	0.19	0.09	0.09	0.05	0.17	4.0	0.61

* *L* = *Lepus*, *P* = *Perognathus*, *D* = *Dipodomys*, and *N* = *Neotoma* (see Sec. 2.1.3).

† Tissue-reference values deducted (Table 3.14).

TABLE 3.20—RELATIVE CONTRIBUTION OF RADIOACTIVE ISOTOPES OF IODINE TO THE THYROID TISSUE DOSE OF NATIVE ANIMALS SAMPLED FROM FALL-OUT-CONTAMINATED AREAS

Shot	Animal species	Distance from GZ, miles	Sampling time (hours after shot)	Sampling time, mr/hr	Total thyroid activity, %		
					I^{131}	I^{133}	Other
Turk	Bobcat	12	192	<0.5	100		
	Kangaroo rat	1	264	50	100		
	White-footed mouse	1	240	50	100		
Apple	Pocket mouse	20	30		7	90	3
Post	Pocket mouse	6	27	12	12	88	Trace
	Pocket mouse	6	27	12	9	91	Trace
	Kangaroo rat	6	27	12	8	92	Trace
	Kangaroo rat	6	27	12	9	91	Trace
	Kangaroo rat	6	54	12	20	70	9.5
	Ground squirrel	6	54	12	23	70	7
	Jack rabbit	7	63	5	32	68	Trace

rabbits and kangaroo rats sampled in the same and in adjacent areas. Also of interest is the persistence of the thyroid burden, which, after 25 days, is still roughly 30 per cent of the burden measured on D-day, even though the activity is due to I^{131} with a radiological half life of 8.04 days.

The levels of fall-out contamination were five to ten times lower for Apple shot than those for Met shot (documented by Project 27.2). This was reflected in the activity of the tissues from animals collected at various distances from GZ (Tables 3.16 and 3.17).

The biological accumulation of fission products as a result of contamination by the Apple II detonation (Table 3.18) tended to be greater as the sampling site approached the midline of fall-out. This phenomenon appears to be typical of all fall-out patterns. In the case of the Apple II fall-out pattern, the variations that occur are partly attributable to the apparent lack of a single well-defined midline of fall-out at the distances studied.

Table 3.19 summarizes data collected by spot sampling following various Operation Teapot detonations. Thyroid activity was detected in all cases, regardless of what level of fall-out occurred. Thus, the thyroid becomes a qualitative indicator as to whether or not biologically available fall-out is present during the first week or two following a detonation. Efforts were made in the field laboratory to resolve the various isotopes of radioiodine in the thyroid by analyses of the radioactive decay curves of thyroid tissue; these data are summarized in Table 3.20.

Generally, the radioactivity found in the GI tract was markedly higher than that in the lung at all time periods studied. High levels of activity were detected in the thyroid tissue. Muscle tissue generally contained the lowest amount of radioactivity.

3.2.3 Serial Sampling of Native Animals from Fall-out-contaminated Environments

Table 3.21 summarizes the changing levels of fission products in a population of animals collected daily for 7 days and again on the fifteenth day for an environment 12 miles from GZ which was contaminated by radioactive fall-out from Apple II shot.

Although the levels of radioactivity were variable among the different species of animals, measurable amounts of radiation persisted in the tissues for at least 2 weeks after fall-out. In the case of the thyroid gland, the tissue burden actually increased during the 2-week sampling period. The high activity levels of the GI tract (compared with those of the lung, in addition to the rapid decline in lung activity by D+4 days) suggest that inhalation is of secondary importance to ingestion as a path of uptake of the metabolized fission products.

Table 3.22 shows the radioactivity in tissues of jack rabbits serially collected from certain areas contaminated by radioactive fall-out from Apple I and Met shots. Even 6 months after contamination, tissue burdens of twice the normal value were apparent, except in the case of the lung and the GI tract. A striking example was bone, which, 6 months following contamination by Met shot, showed a tissue burden of almost six times the normal value.

The radioactivity in the bone is further documented, in terms of radiostrontium content, in Table 3.23. It will be noted that, in the case of both Apple I and Met shots, the radiostrontium content of the bone tended to increase with time, suggesting that the strontium burden of the bone was the result of chronic exposure to residual fall-out rather than to a single exposure at the time of fall-out. The occurrence of radiostrontium in the bones of animals collected along the midline of several residual fall-out patterns from October to December 1955 is summarized in Table 3.24. Of particular interest is the high radiostrontium content of the bone at Enterprise, Utah, 133 miles from Met shot GZ; at Steptoe, Nevada, 155 miles from Apple II shot GZ; and at Mormon Mesa, Nevada, 94 miles from Tesla shot GZ.

Because of the low level of radiostrontium, it was desirable to report the data in Tables 3.23 and 3.24 in disintegrations per minute rather than in microcuries. Some error may be anticipated since the data reported were prepared at two different time intervals, October to December 1955 and June to July 1956. Since analysis of radioactive decay curves has revealed the presence of varying amounts of Sr^{89}, the length of time during which samples are stored before processing, as well as the time at which samples are obtained from the field, can influence the relations described in Table 3.23. Such errors are not inherent in the data of Table 3.24 since, in these cases, all analysis and sampling were done during comparable time intervals.

3.2.4 Inhalation Studies

Dutch rabbits, prelocated and exposed in restraining cages to various conditions of the initial fall-out of two detonations, have failed to yield definitive data as to whether or not inhalation contributes significantly to the total-body burden. Radioanalysis of the various tissues of the experimental animals used for inhalation studies during Met and Apple II shots has revealed radioactivity less than twice the level of the control series; thus it appears that inhalation is of secondary importance to ingestion as a path of fission-product absorption. These conclusions[2] were in agreement with data collected by Project 37.3.

It should be noted that, in terms of gross beta activity, the external contamination on the skin and pelt of the animals has been observed to account for between 22 and 62 per cent of the total beta radioactivity associated with the animal. In attempting to reconstruct the dynamics of fall-out assimilation by animals, the skin as a source of fall-out material to animals during preening should not be overlooked.

TABLE 3.21—AVERAGE BETA ACTIVITY IN TISSUES OF NATIVE ANIMALS SERIALLY SAMPLED ALONG THE MIDLINE OF APPLE II SHOT FALL-OUT, 12 MILES FROM GZ

Animal species*	No. of animals	Distance from midline, miles	Sampling time (days after shot)	Average activity extrapolated to time of sampling (wet-tissue basis),† mμc/g						
				Lung	Liver	Kidney	Muscle	Femur	Thyroid	GI
D. merriami[1]	1	0	D-day	0.26	1.72	1.03	0.23	0.13	1.4	8.2
D. microps	1	0		0.05	0.74	0.22	0.15	0.17	3.9	20.6
L. californicus[2]	3	4.0		0.21	0.16	0.19	0.07	0.35	1.3	21.1
L. californicus	1	4.5	1	0.17	0.14	0.14	0.17	0.16	3.4	5.1
S. auduboni[3]	1	3.0		2.00	1.53	2.12	1.21	0.93	122.4	28.1
P. longimembris[4]	5	0		0.29	1.82	1.13	1.33	1.06		39.6
C. leucurus[5]	1	0		0.19	1.62	0.89	0.31	1.11	36.1	7.7
S. auduboni	1	0.5	2	0.28	0.15	0.33	0.28	2.10	38.6	1.5
D. microps	2	0		0.04	0.31	0.08	0.03	0.25	14.1	1.1
D. microps	6	0	3	0.12	0.47	0.27	0.08	0.33	17.1	3.7
L. rufus[6]	1	0.5		0.14	0.28	0.17	0.10	0.34	77.3	8.2
D. microps	2	1.5	4	0.05	0.23	0.09	0.03	0.28	41.9	1.4
P. longimembris	13	0		0.05	0.43	0.14	0.46	0.24		3.2
P. formosus	1	0		0.06	1.00	0.38	0.32	0.63	24.8	4.3
D. microps	1	0	5	0.07	0.30	0.12	0.04	0.14	4.78	3.7
P. longimembris	1	0		0	0.11	0.15	0.07	0.14	18.7	3.9
C. leucurus	2	0		0.06	0.23	0.12	0.03	0.20	88.6	1.7
O. torridus[7]	1	0		0.07	0.14	0.13	0.13	0.50	7.10	1.0
L. californicus	1	0	6	0.05	0.12	0.12	0.03	0.21	6.28	5.8
S. auduboni	1	0.5		0.13	0.32	0.14	0.03	0.14	1.15	2.9
D. microps	1	0		0.11	0.13	0.09	0.01	0.11	27.3	0.7
P. longimembris	1	0		0	0	0	0	0		1.9
C. leucurus	1	0		0.04	0.07	0.05	0.04	0.16	98.2	0.7
P. maniculatus[8]	1	0		0.33	0.69	0.39	0.42	23.04	113.3	3.9
L. californicus	1	2.5	15	0.02	0.07	0.05	0.01	0.14	34.3	1.4
S. auduboni	1	2.0		0.11	0.11	0.09	<0.01	0.10	29.6	1.0

*Genera: 1. *Dipodomys*, 2. *Lepus*, 3. *Sylvilagus*, 4. *Perognathus*, 5. *Citellus*, 6. *Lynx bobcat*, 7. *Onychomys*, and 8. *Peromyscus* (see Sec. 2.1.3).

† Tissue-reference values deducted (Table 3.14).

TABLE 3.22—AVERAGE BETA ACTIVITY IN TISSUES OF JACK RABBITS SERIALLY COLLECTED FROM SELECTED AREAS CONTAMINATED BY FALL-OUT FROM APPLE I AND MET SHOTS

Distance from GZ, miles	No. of animals	Sampling time (days after shot)	Average activity extrapolated to time of sampling for fresh tissue,* mμc/g					
			Lung	Caecum	Liver	Kidney	Muscle	Bone
			Apple Shot					
63	1	2	0.074	15.6	0.158	0.136	0.064	0.146
	2	230	0.001		0.003	0.003	0.004	0.004
80	4	2	0.116	16.5	0.817	0.067	0.385	0.639
	2	3	0.061	4.35	0.990	0.055	0.376	0.103
	5	10	0.021	0.606	0.021	0.018	0.010	0.060
	5	220	0.001	0.006	0.003	0.002	0.003	0.003
			Met Shot					
140	1	1	0.222	4.41	0.655	1.35	0.022	1.85
	1	2	0.531	81.1	0.529	0.606	0.020	0.711
	5	187	0.001	0.004	0.002	0.002	0.002	0.013
Average "normal" activity†	21	Preseries	0.001	0.007	0.001	0.001	0.001	0.002

*Tissue-reference values deducted (Table 3.14).
†See Table 3.14.

TABLE 3.23—AVERAGE RADIOSTRONTIUM IN FEMUR OF JACK RABBITS SERIALLY COLLECTED FROM SELECTED AREAS CONTAMINATED BY FALL-OUT FROM APPLE I AND MET SHOTS

Distance from GZ, miles	No. of samples	Sampling time (days after shot)	Beta content of bone (wet-tissue basis)		
			Total, d/m/g	Radiostrontium d/m/g	Radiostrontium %
		Apple Shot			
63	1*	2	9.23	1.52	16.5
	2†	230	10.3	2.68	22.1
80	5*	2	6.01	0.79	
	1*	10	8.90	0.82	9.3
	5†	220	6.42	1.78	28.6
		Met Shot			
140	1*	1	13.1	2.82	18.4
	1*	2	10.6	2.46	23.3
	3†	187	29.9	12.12	40.2

*Date of analysis, June to July 1956.
†Date of analysis, October to December 1955.

TABLE 3.24—AVERAGE RADIOSTRONTIUM IN FEMUR OF JACK RABBITS SAMPLED ALONG THE MIDLINE OF THREE RESIDUAL FALL-OUT PATTERNS FOLLOWING OPERATION TEAPOT (OCTOBER-NOVEMBER 1955)

Description of sampling conditions			Beta content of bone (wet-tissue basis)		
				Radiostrontium‡	
Miles from GZ	Relative dose rate* at collection, mr/hr	No. of animals	Total,† d/m/g	d/m/g	%
		Met Shot			
44	1.1	3	12.0	2.56	21.3
83	0.42	3	18.7	4.20	29.8
133	0.33	10	29.6	12.1	40.8
176	0.19	3	11.5	4.05	35.2
199	0.09	6	17.1	5.50	32.1
232	0.07	3	12.0	5.40	45.0
417	0.08	3	13.8	2.67	19.3
		Apple II and Turk Shots			
5	5.5	2	10.8	3.55	32.8
20	0.4	4	13.4	2.62	19.5
106	0.13	3	7.0	5.62	80.2
130	0.11	3	6.1	4.11	67.3
155	0.14	3	12.5	4.58	36.6
		Tesla and Apple I Shots			
12	0.5	3	8.7	2.75	31.6
44	1.1	3	12.0	2.51	20.9
66	0.08	3	7.3	2.92	40.0
94	0.05	3	11.9	4.94	67.7
136	0.01	4	9.2	2.04	44.4

* Values above background were determined by a Nuclear Model 2610A G-M survey meter, with the window open, 1 in. from the ground.

† Tissue-reference values not deducted (see Sec. 3.2.3).

‡ Date of analyses, October to December 1955.

REFERENCES

1. L. Baurmash et al., Distribution and Characterization of Fall-out and Air-borne Activity from 10 to 160 Miles from Ground Zero, Spring 1955, Operation Teapot Report, WT-1178, 1958.
2. G. V. Taplin et al., Evaluation of the Acute Inhalation Hazard from Radioactive Fall-out Materials by Analysis of Results from Field Operations and Controlled Inhalation Studies in the Laboratory, Operation Teapot Report, WT-1172, 1958.

Chapter 4

DISCUSSION

4.1 PLANT AND SOIL EXPERIMENTS

4.1.1 Foliage Retention of Fall-out Materials with Respect to Particle-size Deposition, Distance from GZ and Midline of Fall-out, and Leaf-surface Characteristics

Evidence that the predominant size of fall-out particles retained on plant foliage generally ranged from 0 to 44 μ in diameter suggested that the degree of foliage contamination might be a function of the mechanical distribution of fall-out particles of this size range in the fall-out pattern. To demonstrate this relation, plant contamination, total soil contamination, and the radioactivity contributed by the less than 44-μ particle-size fraction were plotted with respect to distance from GZ for Tesla, Apple I, Met, and Apple II shots (Figs. 4.1 to 4.4). The plotted data are for plants exhibiting similar leaf-surface morphology and for soil data collected from the same locations at comparable distances from the midline of fall-out at each distance from GZ.

The plots show the correlation between plant activity and the occurrence of the less than 44-μ particle-size fraction near the midline of fall-out at increasing distances from GZ. For Tesla and Apple II shots, there was less radioactivity in the small-sized fractions of fall-out separated from the soil in proportion to the total soil contamination at distances less than 20 miles from GZ than for Apple I and Met shots.

A comparison of the results obtained from Met shot with those obtained from the other shots suggests an influence of the particle size of the surface soil located at GZ on the size ranges of fall-out particles distributed in the fall-out pattern and, in particular, at distances close to GZ. Met shot was detonated on a dry lake bed over soil consisting predominantly of particles in the clay and silt size ranges. The other shots studied were detonated over soil consisting of unconsolidated parent material of rock, sand, silt, and clay size fractions. This predominance of small-sized particles at Met shot GZ is believed to account for the higher levels of activity in the less than 44-μ particle-size fall-out fraction at 20 miles from GZ than the levels observed for the other shots at comparable distances.[1]

Table 4.1 shows the ratios for the millimicrocurie levels of plant activity per gram of dry, native plant material and the microcurie levels of fall-out activity contributed by particles less than 44 μ in diameter for Tesla, Apple I, Met, and Apple II shots relative to distance from GZ. Data for plants with similar leaf-surface characteristics collected near the midline of fall-out were used for these calculations. Also, the assumption was made that the volume per gram of dry plant material (and, consequently, the surface area) was constant for each plant species at various distances from GZ. The plant-activity and the less than 44-μ soil-fraction-activity ratios were comparable at each sampling distance from GZ for each of the shots studied; however, the Met shot ratios were from six to eight times greater than those for Tesla, Apple I, and Apple II shots. This greater ratio for Met shot was attributed to the

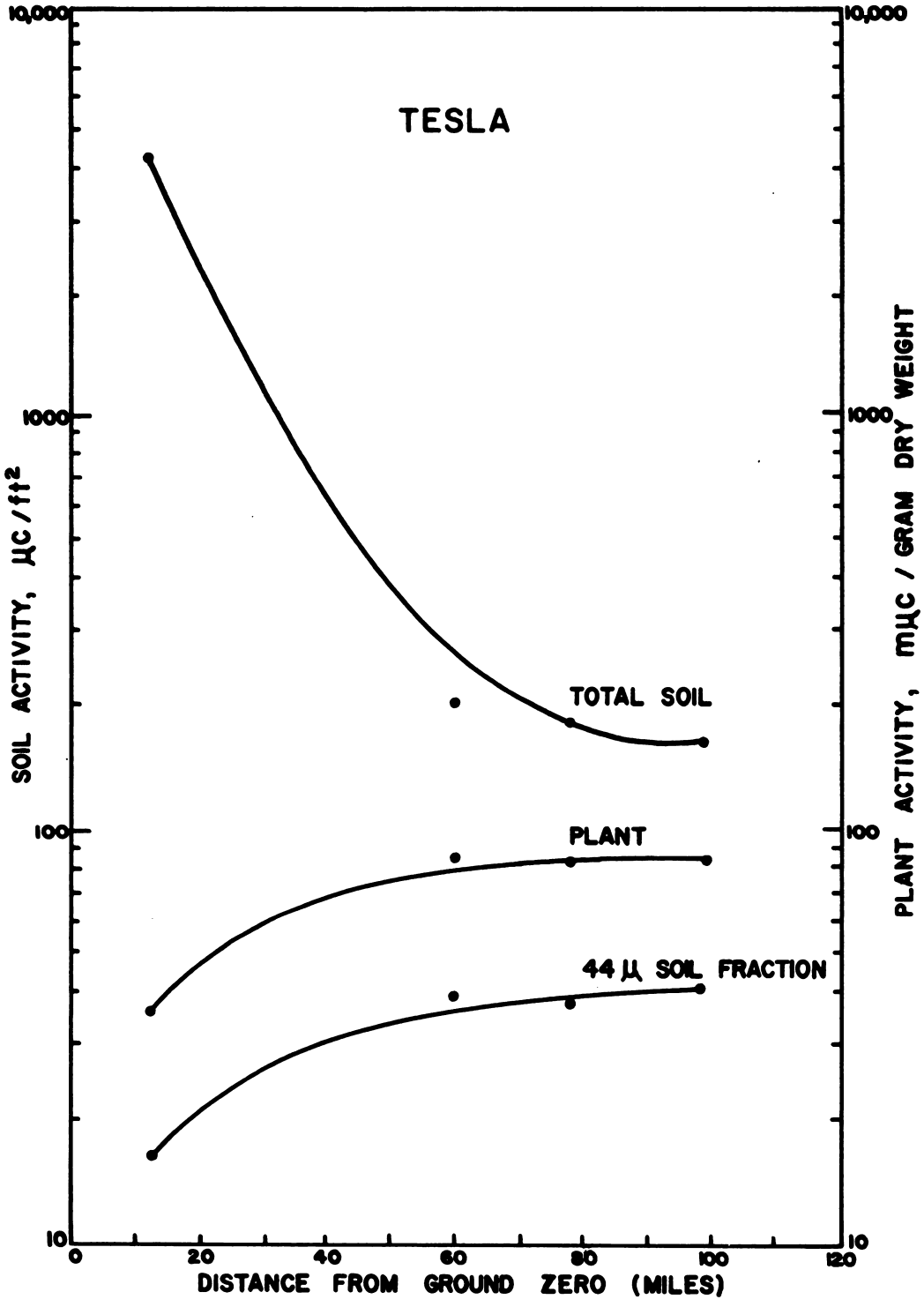


Fig. 4.1—Soil-plant activity relation with respect to distance from GZ, Tesla shot.

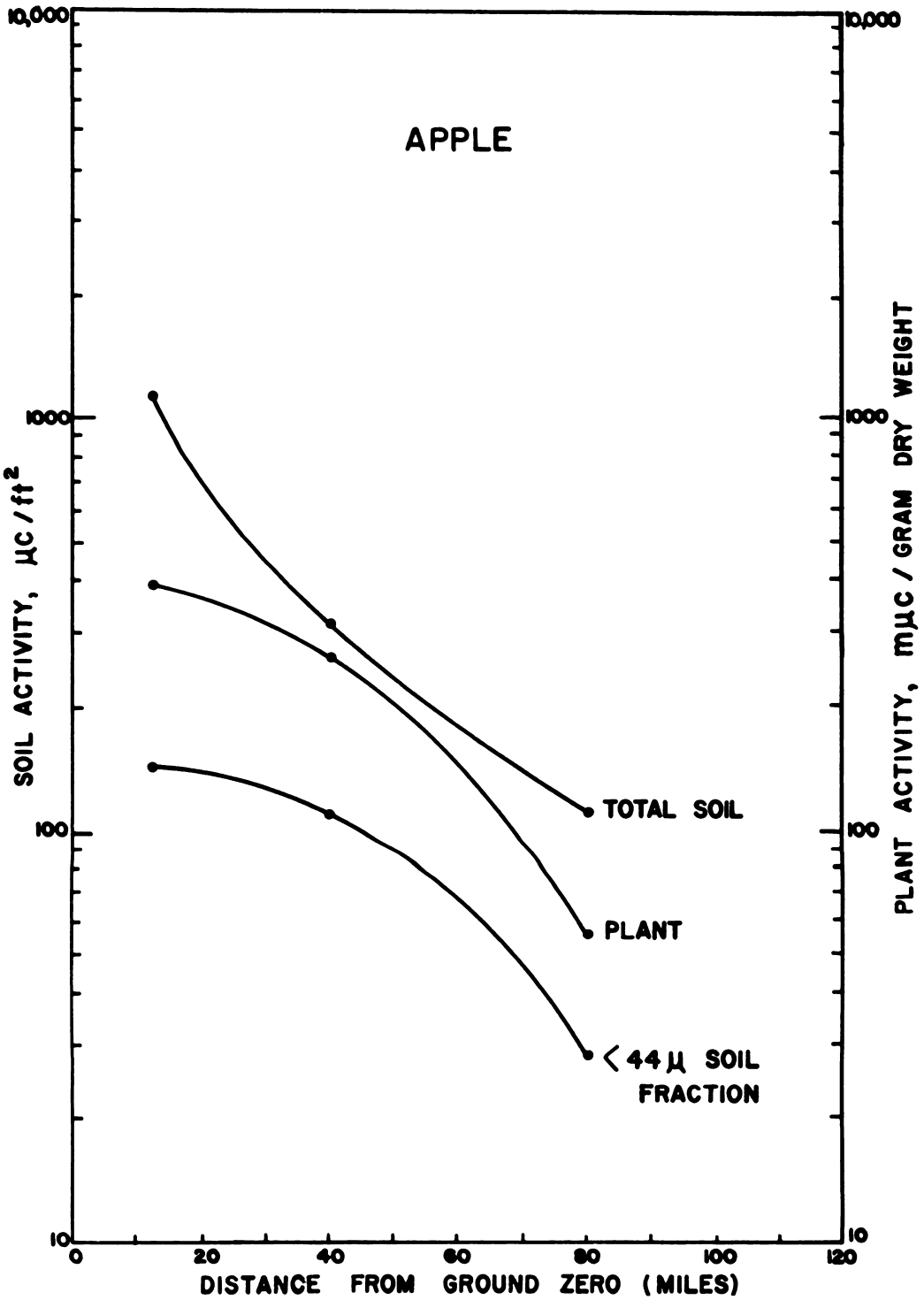


Fig. 4.2—Soil-plant activity relation with respect to distance from GZ, Apple I shot.

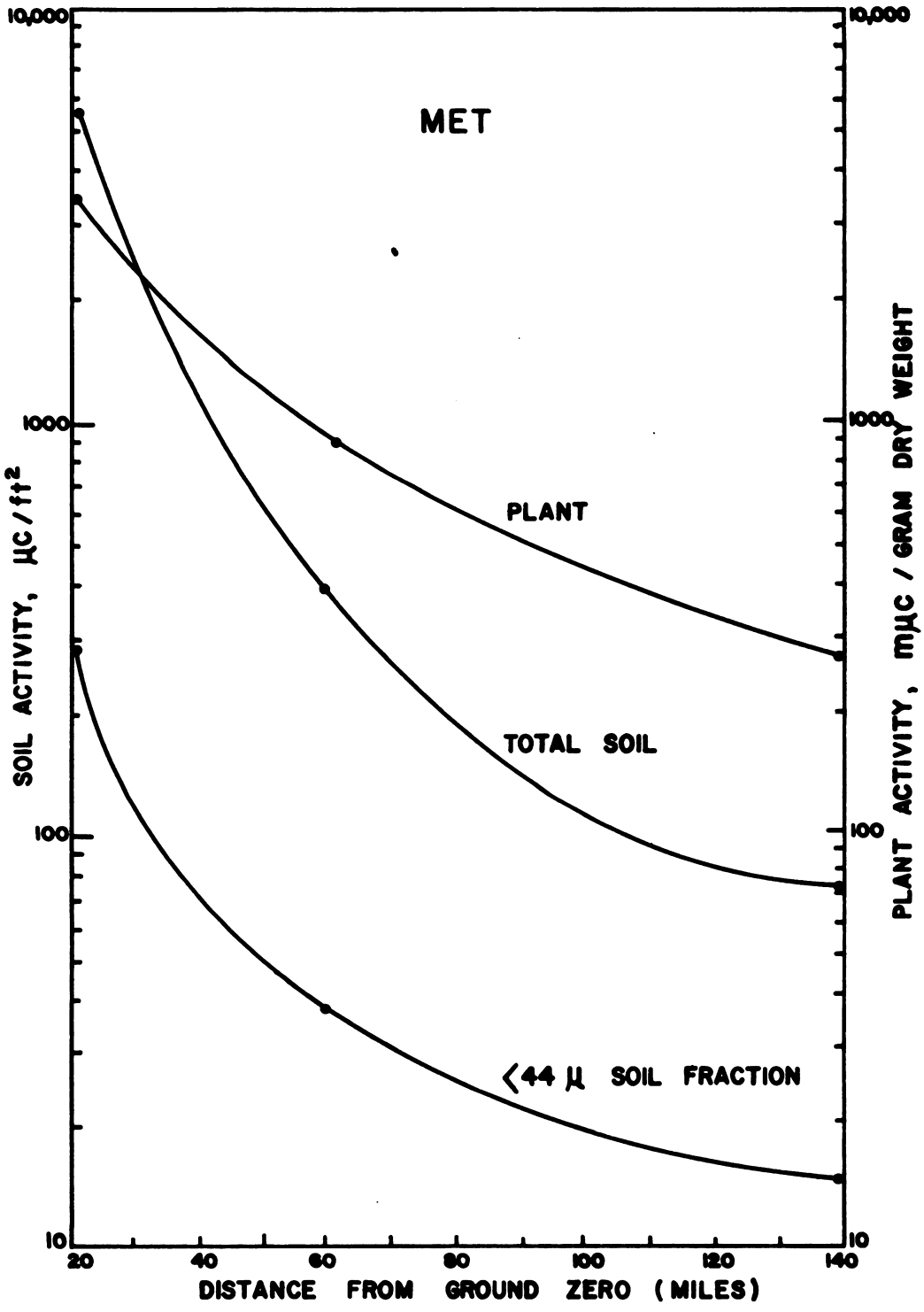


Fig. 4.3—Soil-plant activity relation with respect to distance from GZ, Met shot.

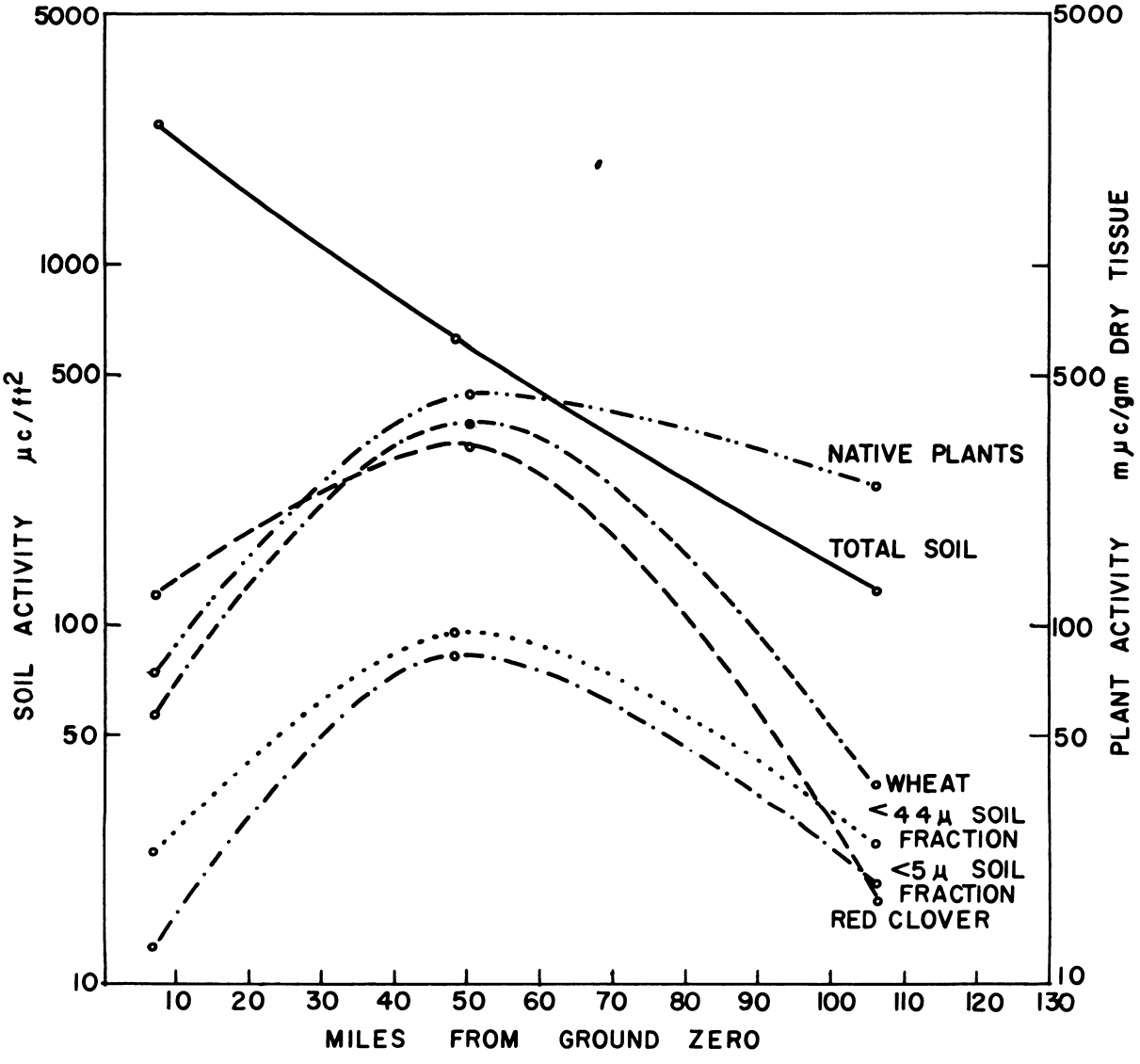


Fig. 4.4—Soil-plant activity relation with respect to distance from GZ, Apple II shot.

TABLE 4.1—RATIOS OF PLANT CONTAMINATION TO THE OCCURRENCE OF THE LESS THAN 44-μ FALL-OUT PARTICLE-SIZE FRACTION AS A FUNCTION OF DISTANCE OF THE SAMPLING LOCATION FROM GZ

Shot	Distance from GZ, miles	Plant activity/g of dry tissue, mμc / <44-μ soil fraction/sq ft, μc
Tesla	12	2.23
	60	2.21
	79	2.26
	96	2.09
Apple I	12	2.78
	40	2.36
	80	2.02
Met	20	12.64
	80	18.00
	140	18.23
Apple II	7	2.39
	48	2.32
	106	2.00

detonation conditions, which resulted in a higher degree of activity per unit area of leaf surface due to the greater number of active particles retained per unit leaf area (see Tables 3.3 to 3.7).

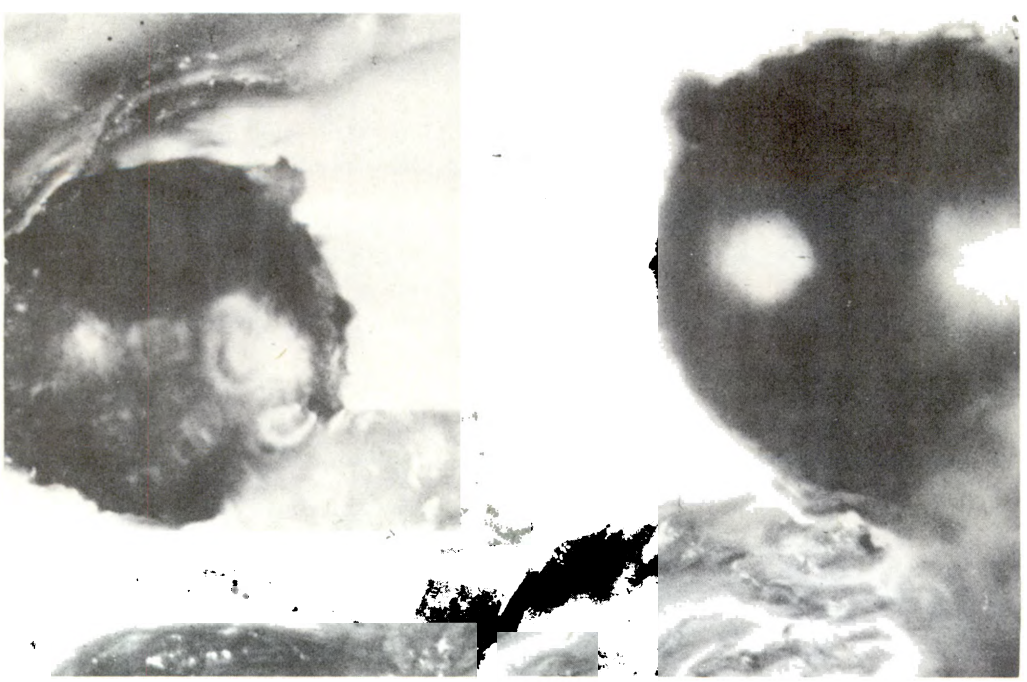
A sufficient number of sampling stations transecting the path of fall-out was contaminated with Apple II shot fall-out at 48 miles from GZ to permit an examination of the relations between plant activity and soil particle-size activity with respect to the lateral distance of the sampling site from the midline of fall-out (see Table 3.1). For this particular shot, there was good correlation between plant activity and both total activity and particle-size ranges less than 44 μ in diameter.

Leaf-retention study techniques developed during Operation Teapot have proved to be an effective means of determining fall-out particle-size distribution on plant foliage. The retention of particles predominantly less than 44 μ in diameter is attributable to the mechanical-trapping characteristics found on most plant leaf surfaces, as shown in Fig. 4.5. The photographs show fall-out particles of less than 100 μ in diameter trapped in the matted hairs on a *Sphaeralcea* leaf surface and on the glutinous surface of a *Viola* leaf. The degree of radioactivity retained on plant foliage is influenced by the area of leaf surface and the mechanical-trapping characteristics of the leaf surface.

An interesting observation made while scanning leaf surfaces for fall-out particles was an apparent radiation burn on a *Sphaeralcea* leaf surface caused by a single fall-out particle of 437 μ in diameter which had a beta-activity level of 0.291 μc at H+12 hr. The hole that was burned into the leaf surface and the particle that was removed from the burned area are shown in Fig. 4.6. Photographs taken while the particle was embedded in the burned area did not give suitable contrast to permit photographic reproduction.

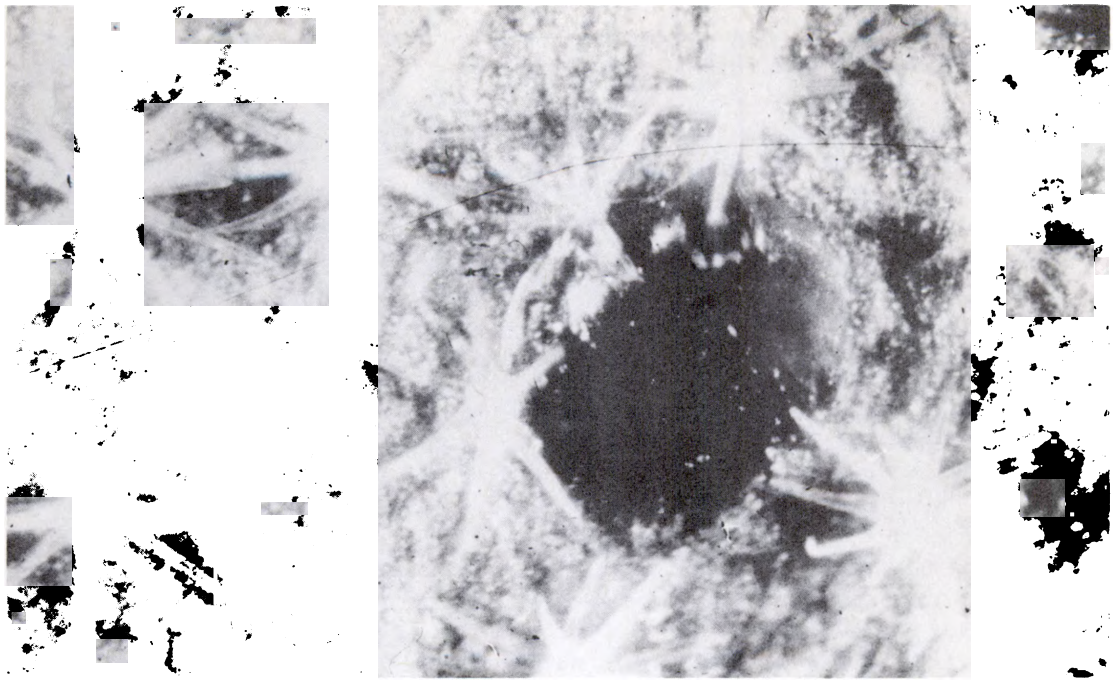
Foliage-retention studies during Operation Teapot have shown that plant leaves are selective collectors of fall-out particles less than 44 μ in diameter and that the degree of radioactive contamination found on plant foliage exposed to fall-out materials is a function of the mechanical distribution of fall-out particles less than 44 μ in diameter at distances within 140 miles from GZ. Data from greater distances were not obtained for the four shots studied. The ratios of plant activity to the less than 44-μ particle size may be expected to vary, depending upon the conditions of the shot detonation. For shots similar to Tesla, Apple I, and Apple II, these ratios may vary from 2 to 3 for distances within 140 miles from GZ. However, the ratio may be from six to eight times greater for shots comparable to Met. The fall-out particle-size range less than 44 μ in diameter should be considered to be of greatest biological significance because of its high degree of retention on the foliage of forage plants. These

(a)

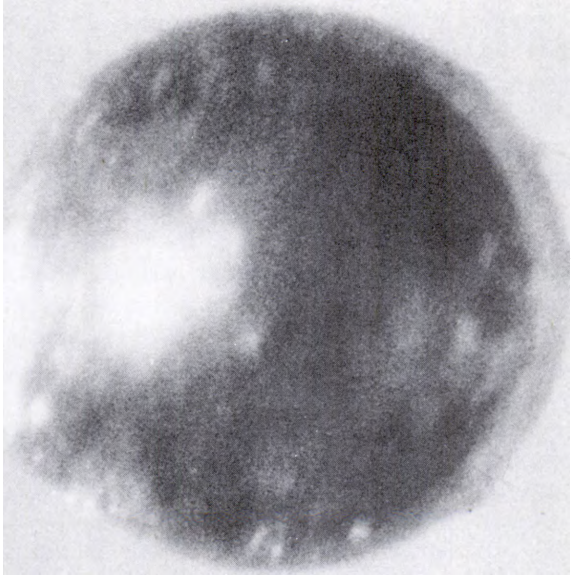


(b)

Fig. 4.5—Fall-out particles less than 100 μ in diameter trapped in matted hairs on the surface of a *Sphaeralcea* leaf (a) and on the glutinous surface of a *Viola* leaf (b).



(a)



(b)

Fig. 4.6—(a) Burned area on the surface of a *Sphaeralcea* leaf in which a 437-μ fall-out particle (b) assaying 0.291 μc at H + 12 hr was embedded.

small-sized particles will be a major source of activity to cattle feeding on forage crops externally contaminated with fall-out materials.

The metabolic accumulation of fission products by plants as the result of foliar absorption of soluble fall-out material has not been observed for plant contaminations within 200 miles from NTS to be attributable specifically to continental detonations in the United States. The British, however, report significant accumulation of fission products by foliar absorption of soluble fall-out debris.[2] Studies of plant contamination by fall-out from the British Operation Hurricane, Monte Bello, showed that foliage collected about 2 weeks after fall-out was contaminated with superficial fall-out particles. Samples collected about 14 months later indicated that considerable contamination by absorbed materials had occurred. The greater part of the early fall-out material collected from the Hurricane test was observed to be soluble in water or in dilute salt solutions. Apparently this was an entirely different type of fall-out material from the relatively insoluble fall-out debris observed during Operation Teapot.

4.1.2 Decontamination of Plant Foliage and the Solubility of Fall-out Materials in Washing Solutions

Data from decontamination experiments have shown that over half of the radioactivity from fall-out materials retained externally on plant foliage can be removed by washing treatments with practical solvents. It would appear that solutions of detergents and chelating agents are the most effective for decontamination purposes. Natural wind action may remove some of the external contamination, depending upon its intensity and duration. Significant amounts of small-sized particles persist on the plant foliage, as the result of being mechanically trapped in the matted hairs and crevices of the leaf surface. The effectiveness of decontamination is influenced by the ability of plant materials to withstand washing treatments and by their particle-retention characteristics.

The washing procedures normally used in the cleaning of fruits and vegetables before packing, shipping, and storing for human consumption will greatly aid in removing fall-out contamination. Certain modifications in washing procedure would increase the removal of fall-out particles; however, this should not be done at the expense of damaging the food products. Fruits and vegetables normally peeled or removed from their hulls or shells in processing may be thoroughly decontaminated. Leafy vegetables contaminated with fall-out materials could be discarded from the human diet, along with fresh fruits and vegetables that have poor keeping qualities after being washed.

Forage crops cannot be thoroughly decontaminated by washing treatments, nor is it practical to do so. This could impose the need for farmers to have stored supplies of livestock feed available to sustain their animals until the activity of the contaminated feed has decayed to a level permissible for livestock feeding because forage crops externally contaminated with fall-out particles are a major source from which animals may assimilate fall-out materials.

Most plant food products consumed by humans can be decontaminated, but meat and dairy products may become sources from which radioactive materials are available. Data on the solubility of foliage-retained fall-out materials in 0.1N HCl suggest that significant amounts of these materials may become soluble in the GI tract upon being ingested.

The degree of solubility is a function of the condition of detonation, and, therefore, the biological hazard from internal emitters ingested in fall-out cannot be generalized. Although the Operation Teapot fall-out materials were observed to be up to 20 per cent soluble in 0.1N HCl, samples of fall-out materials collected from the British Operation Hurricane showed solubilities of up to 97 per cent in water and dilute salt solutions.[2]

4.1.3 Availability of Fall-out Materials to Plants from Contaminated Soils as Influenced by Farm-management Practices

Radioactive materials from fall-out-contaminated soil are available to crop plants, however, the levels of activity taken up from soils contaminated during Operation Teapot were very small in comparison to the levels of fall-out contamination deposited on the soil. Data show that minute levels of activity were taken up by red clover plants up to a period of about 1 year after fall-out occurred. Radioactive materials taken up by way of the root system are

of greater biological significance to plants during the chronic phase following fall-out contamination than they are in the acute phase, during which time fall-out materials retained on the external surface of plant foliage are of greatest biological significance. Of the longer-lived fission products, laboratory experiments have shown that radiostrontium is the most readily available to plants.[3–6] Radiostrontium was found to account for 2 to 5 per cent of the total beta activity in plant ash from a limited number of samples studied, with the remainder of the activity due to naturally occurring radioelements.

Results of experiments to simulate the farm-management practice of using cover crops for green manures and dry crop residues as amendments have shown that organic materials, externally contaminated with fall-out materials and incorporated into soils, are a source of fall-out materials to successive crops. Under conditions where cover crops are contaminated by fall-out materials, they should be removed from the soil and discarded and not turned under for green manure. This also applies to dry crop residues.

Experiments were designed to show the influence of cover crops on the level of fall-out activity deposited at the soil surface and on the successive crop uptake of fall-out materials from the soil; however, the levels of plant activity in crops subsequently grown on bare soil that was exposed to fall-out and on soil on which a cover crop was growing at the time of exposure to fall-out were too low and too erratic to assign any significance to the treatments. In a number of cases, the presence of cover crops reduced the deposition of fall-out materials on the soil surface to about one-half of the level deposited on the bare soil; however, this difference in fall-out activity deposition could not be accounted for in the radioassay of the cover crops removed from the soil (Table 4.2). Data showed that the activity of the red-clover cover crop accounted for only 1 to 5 per cent of the reduced activity.

The dimensions of the exposed soil flats were approximately 12 by 18 in., and the height of the plant material varied from about 8 to 16 in. above the soil surface. Under these conditions, it would appear that some relatively large fall-out particles were lodged temporarily on the plant foliage, and then the particles were flicked off by wind action and deposited on the surface of soil outside the portable flat rather than on the experimental soil surface in the flat. A similar movement of particles could also occur in a field of growing plants, but the activity would ultimately reach the soil surface on which plants were growing. It appears that either portable flats with a greater soil area or natural agricultural areas might give a better assessment of the influence of cover crops on surface-soil contamination.

Another important factor should be pointed out with respect to this experiment. The data given in Table 4.2 show that a greater surface-soil activity was deposited in at least three instances in which cover crops were growing on the soil than was deposited on the bare surface. These results also suggest that the apparent differences in fall-out deposition might reflect natural variations in fall-out deposition on the soil surface since it has been shown that fall-out deposition may vary by a factor of 2 or more between replicates of surface soil taken a few feet apart from any given sampling area.

4.2 ANIMAL UPTAKE

The problem of assessing the biological hazard of radioactive fall-out may be arbitrarily divided into two parts: (1) the acute or immediate hazard arising primarily from external radiation and secondarily from the metabolism of certain fission products and (2) the chronic or long-term hazard arising primarily from the metabolized fission products and secondarily from external radiation. The division of the problem is real; the exact duration of each phase is not.

Data are presented in this report which emphasize the fate and persistence of the metabolized fission products for both the acute and chronic aspects of environmental contamination by radioactive fall-out.

4.2.1 Source of Metabolized Fission Products

The fact that the lung may have been an important source from which radioactive materials were available to other tissues cannot be ignored since the activity per unit weight of liver, kidney, muscle, and femur generally were as closely related to the lung as they were to the GI tract. Observations that the radioactivity in the GI tract was several orders of

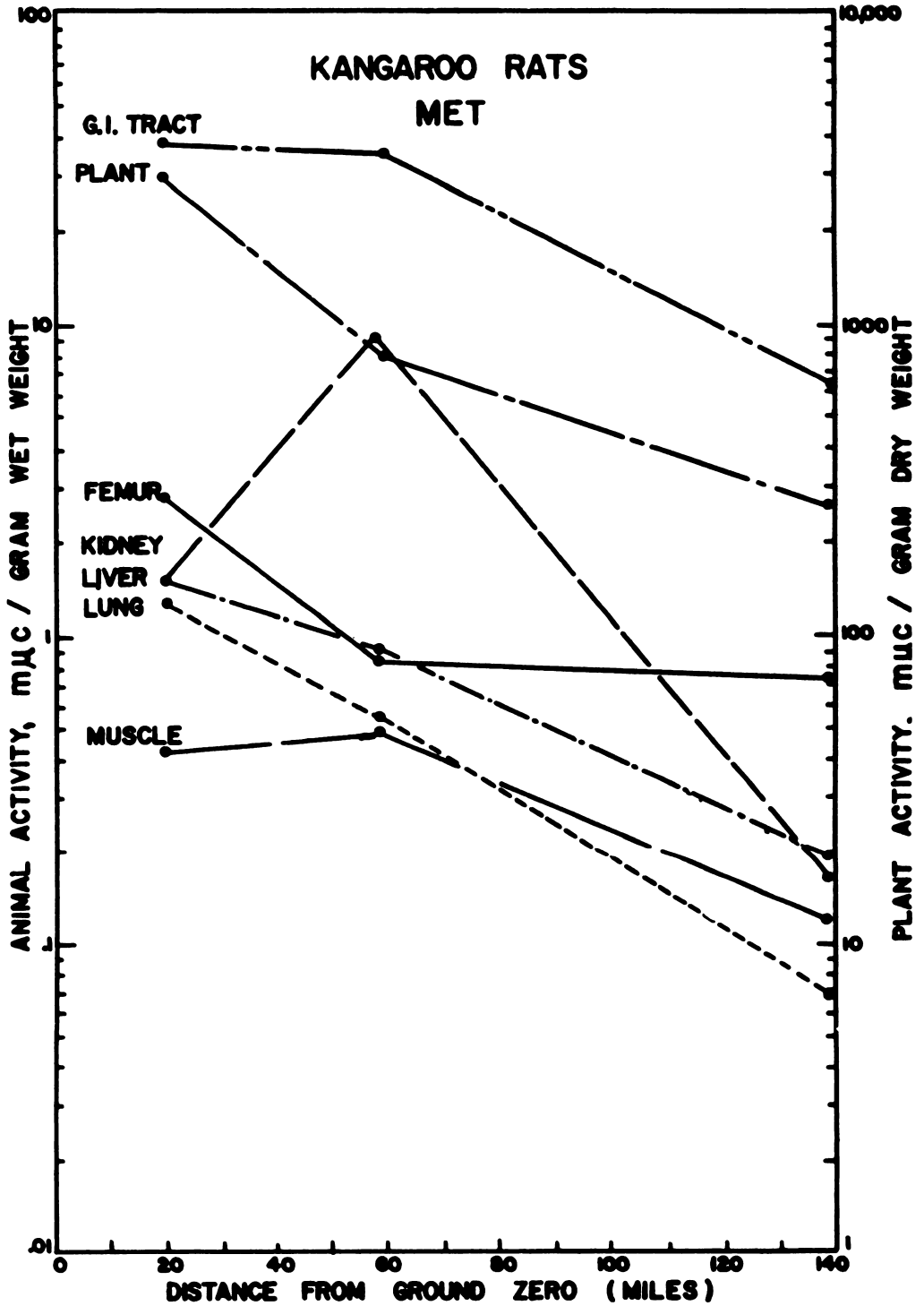


Fig. 4.7—Fission-product distribution in tissues from kangaroo rats sampled after grazing two nights (D-day to D+1 day) in Met shot fall-out area as a function of distance of the sampling location from GZ.

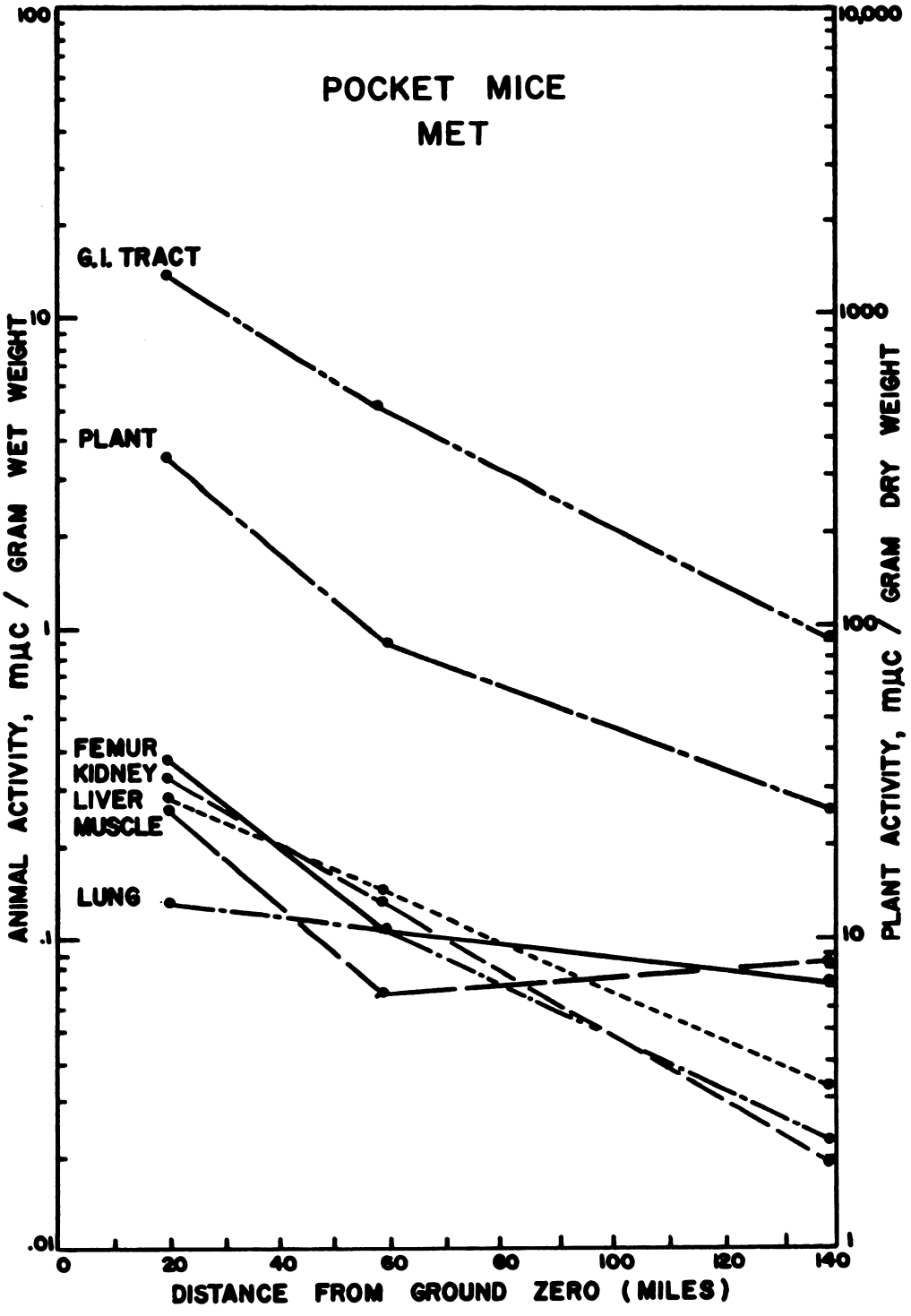


Fig. 4.8—Fission-product distribution in tissues from pocket mice sampled after grazing two nights (D-day to D+1 day) in Met shot fall-out area as a function of distance of the sampling location from GZ.

TABLE 4.2—INFLUENCE OF COVER CROPS ON THE REDUCTION OF FALL-OUT MATERIALS DEPOSITED ON TUJUNGA SOIL EXPOSED TO PRIMARY FALL-OUT FROM APPLE II SHOT

Soil flat location		Soil activity, μc/sq ft			Fall-out contamination of total cover crop, μc/sq ft of soil surface	
Distance from GZ, miles	Distance from midline, miles	Bare soil	Under red clover*	Under wheat*	Red clover	Wheat
7	2.4E	74.5	27.3	15.0	0.242	1.163
	0.6E	2070.1	1053.0	1487.0	2.352	4.113
	0.9W	2475.5	3344.0	2123.0	1.944	2.000
48	3.2E	495.9	201.0	210.0		11.953
	0.8E	646.6	504.0	251.0	4.219	15.091
	2.2W	490.1	217.0	274.0	3.289	4.898
	5.2W	108.7		50.1	1.292	3.142
	8.4W	34.0	32.0	51.0	0.273	0.574
	11.2W	20.0	9.0	9.0	0.471	1.143
106	34.0W	19.9	8.2	8.2	0.253	1.168
	38.0W	1.2	1.7	6.4	0.238	0.475
	41.5W	1.7	<1	<1	0.216	0.485

*Soil on which a cover crop was growing at the time of exposure to fall-out.

magnitude greater than the radioactivity found in the lung suggest that the lung was only a minor source from which radioactive materials may become available to the animals. This conclusion seems further validated by the lack of uptake of fission products by Dutch rabbits held in restraining cages in the path of fall-out.

There were four sources from which fission products were absorbed by the gut: (1) the ingestion of contaminated forage, (2) the ingestion of fall-out from the pelt during preening following dust baths, (3) the ingestion of fall-out while burrowing or digging, and (4) the swallowing of material cleared from the lungs and nasopharynx.

Of the four possibilities, the best correlation during the first two weeks following fall-out seemed to exist between the levels of radioactivity occurring in the GI tract and the levels of radioactivity occurring on the plant material upon which the animal fed (Figs. 4.7 and 4.8). Since the nature of the contamination on the plant material has been shown to be predominantly the less than 44-μ-size fall-out particles (Figs. 4.1 to 4.4), it follows that the animal was ingesting primarily the less than 44-μ fraction of gross fall-out selectively collected by the plant leaves.

The effect that this latter point can have on estimating the biological significance of fall-out can be shown by comparing the occurrence of radiostrontium in fall-out material[1] (Table 4.3). Note that, although the amount of radiostrontium in the less than 44-μ-size material was small compared to the gross fall-out because of its solubility characteristics, the actual number of disintegrations per minute of radiostrontium available for biological cycling came primarily from the less than 44-μ material. Note also that relatively more radiostrontium than gross fission product was removed by ammonium-acetate leaching. This indicates that the radiostrontium was primarily on the surface of the particles, and it was therefore more relatively available than some of the other fission products.

4.2.2 Animal Uptake as Influenced by the Position of the Sampling Site Within the Fall-out Pattern (D-day to D+2 days)

In discussing this topic, it should again be stressed that care must be taken to compare only those animals with similar food habits and animals sampled from similar locations with respect to the midline of fall-out (see Sec. 3.2.2). The tissue burdens of mixed fission products relative to the distance of the sampling site from GZ are shown in Figs. 4.7 and 4.8 for kangaroo rats and pocket mice sampled from environments contaminated by Met shot fall-out.

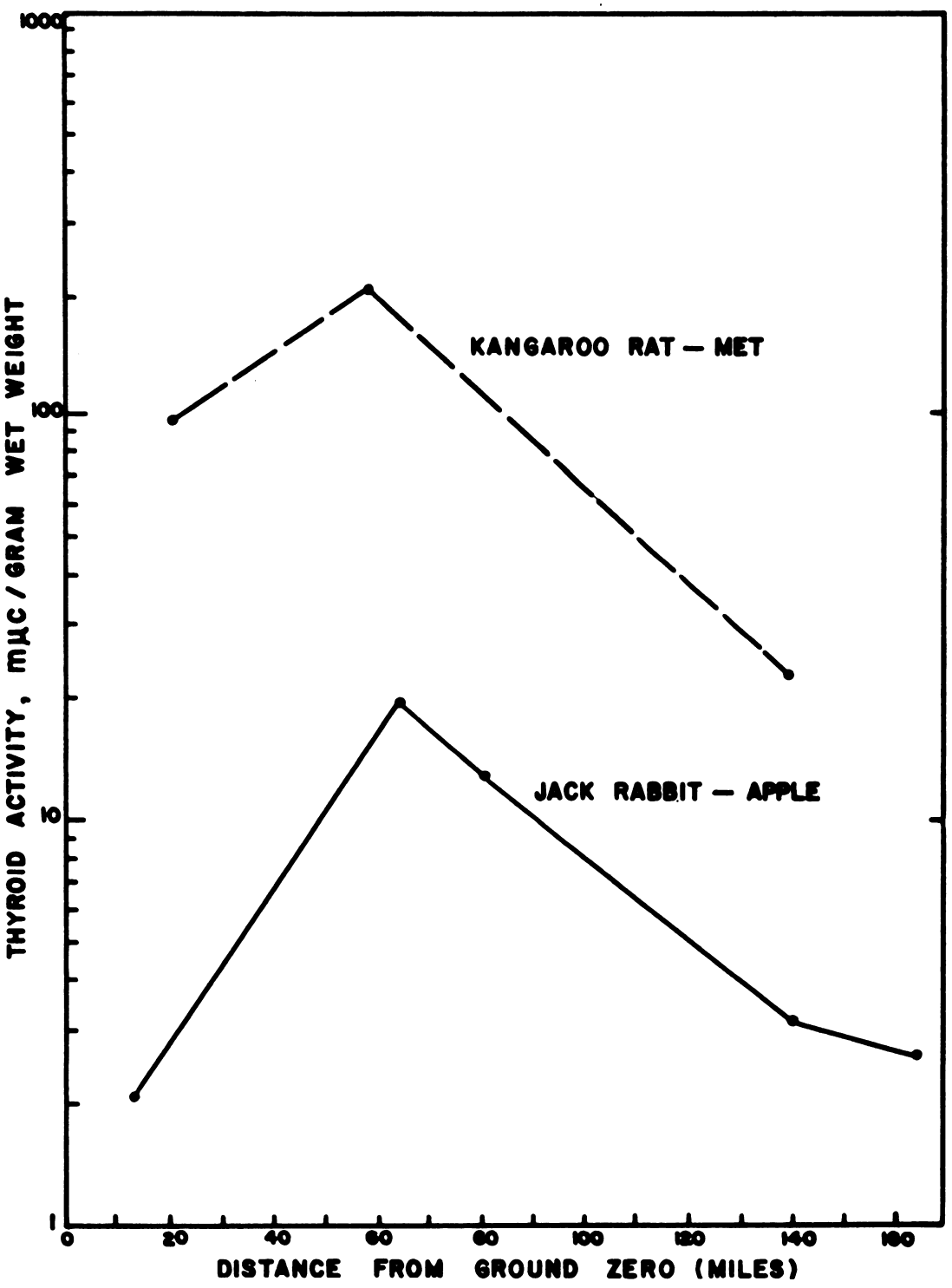


Fig. 4.9—Occurrence of radioiodine in the thyroids of kangaroo rats and jack rabbits contaminated by radioactive fall-out as a function of distance of the sampling location from GZ.

TABLE 4.3—OCCURRENCE AND BIOLOGICAL AVAILABILITY* OF RADIOSTRONTIUM IN FALL-OUT MATERIAL FROM MET SHOT

Distance of sampling site from GZ, miles	Size of fall-out particles,† μ	Total activity, d/m/sq ft	Biologically available activity		Total radio-strontium,‡ d/m/sq ft	Biologically available radiostrontium		Total activity available as radio-strontium, %
			d/m/sq ft	%		d/m/sq ft	%	
20	>44	98,000	5,980	6.09	856	571	66.7	0.582
	250–297	637,000	355	0.06	6,250	180	2.88	0.028
	297–350	369,500	274	0.07	8,730	34.1	0.39	0.009
58	>44	49,200	1,555	3.16	344	106	30.7	0.214
	125–177	101,000	743	0.74	812	40.6	5.00	0.040
	177–250	47,950	364	0.76	849	128	15.1	0.268
140	>44	20,900	550	2.63	991	68.0	6.86	0.325
	88–125	19,450	210	1.08	137	24.9	18.2	0.128
	125–177	2,025	197	9.70	154	19.7	12.8	0.973

*Biological availability estimated by ammonium-acetate leaching.
†These data[1] correspond to the particle-size ranges given in Tables 3.6 and 3.7 of Report WT-1178.
‡Time of analysis of all samples was from January to February 1957.

The levels of plant contamination at each of the sampling areas are included since this is the most probable source of the metabolized fission products present in the animal tissues.

In general, the radioactivity of all tissues decreased with distance from GZ. The activity per unit weight of the femur, however, remained relatively constant, instead of declining, for both species of animals from 60 to 140 miles from GZ. The kidney of the kangaroo rat also showed an unusual pattern with a high level of radioactivity per unit weight at 58 miles, as compared to the kidney at 20 and 140 miles. The high value at 58 miles was a mean determined from 23 specimens demonstrating a low standard deviation. This suggests that the phenomenon is real, although no such variation was observed for the pocket mouse. It is possible that this observation is, in some way, associated with the peculiar physiology of the kangaroo rat, i.e., the increased renal reabsorption of water.

The thyroid gland demonstrated a pattern of accumulation similar to the kidney (Fig. 4.9). The radioactivity present in thyroid tissue has been satisfactorily identified as radioiodine (see Table 3.20); and, because of the biological importance of iodine (i.e., in terms of normal physiological requirements), it appears proper to treat the occurrence of thyroid activity or radioiodine separately. For the cases illustrated, it appears that the thyroid burden of radioiodine was greater at 63 miles than at either 12 or 140 miles from GZ. Note that Fig. 4.9 shows similar data resulting from fall-out contamination by two separate detonations. Although the conditions of detonation were very different, the peak thyroid contamination in both cases occurred at about 63 miles. An important consideration to be discussed in Sec. 4.2.3 is that sampling occurred within 24 to 48 hr following fall-out, or almost 2 weeks prior to the time at which the maximum values would be predicted to occur in any one location.

4.2.3 Persistence of Fission Products in Rodent and Jack Rabbit Populations

Table 3.22 shows the persistence of fission products in various tissues from local jack rabbit populations serially sampled over a 7-month period. The average tissue burdens were still above normal at the end of that period. Attempts to estimate the radioactive content of the bone above normal demonstrated that it would be accounted for in terms of radiostrontium and its daughter product. Furthermore, although the amount of radiostrontium in the bone was constant between D+2 and D+10 days, it increased from two to five times within 6 months (see Table 3.23), thereby demonstrating the relative importance of the chronic dose over the acute dose in influencing radiostrontium assimilation.

Comparisons were made among the activities of various tissues from jack rabbits, cottontail rabbits, kangaroo rats, and pocket mice sacrificed on different days after fall-out from an

area 12 miles from GZ (see Table 3.21). Since the serial samplings generally yielded only one replicate of each species, the reliability of the data is limited in this respect. The importance of comparing only specimens sampled from the same location at the same time is again emphasized by the variations in activity with respect to time, demonstrated by *R. megalutus* and *P. maniculatus* sampled from the same location but at 36-, 44-, and 72-hr time intervals following fall-out contamination (see Table 3.17).

The activity of the various tissues from the three different species was rather closely related to the activity of the GI tract during the 2-week sampling period. This suggests that the initial body burdens of fission products are dominated by isotopes with short biological half lives. Therefore, the tissue burden is dependent upon replenishments presumably from the GI tract. Consequently, over a short period of time, it is not surprising that the fission-product content of various tissues appears related to the concentration of fall-out material in the GI tract. The relative decrease in activity of these tissues serially sampled from the rodent population did not markedly deviate from that of the radioactive beta decay of the mixed fission products measured by Project 37.2. Figures 4.10 and 4.11 show the relative persistence of fission products in the various tissues of kangaroo rats and pocket mice serially sampled from the midline of Apple I shot fall-out. Similar figures cannot be shown for the jack rabbit and cottontail rabbit because their sites of collection were not comparable from day to day with reference to the midline of fall-out. The data given in Table 3.21, however, do indicate a similar trend for these two species.

The activity in the femur of the kangaroo rat population increased up to the third day after fall-out, and then it decreased. During the 6-day period that kangaroo rats were sampled, the activities of tissues (other than the femur) were closely related to the activity of the GI tract. Assuming ingestion as the principal source of contamination, the curves for the population of kangaroo rats and pocket mice indicated a rapid equilibrium between the absorbed activity and that passing through the gut may have been established for these rodents within the first 2 days after fall-out. During the 6-day sampling period, there appeared to be little evidence of biological concentration of fission products in terms of gross beta activity.

Figure 4.12, however, shows the persistence of radioiodine in the thyroids of native animals serially sampled from the approximate midline of Apple II shot fall-out (see Table 3.21). The thyroid burden increased gradually throughout the 15-day sampling period. This build-up of thyroid activity, which corresponds to similar phenomena described at the Hanford Works, is considered to reflect the time necessary for the iodine in the thyroid and in the food supply to reach equilibrium. The early thyroid burden is largely estimated by the accumulation of the relatively short-lived isotopes of iodine, whose fission yield is approximately twice that of I^{131}. Iodine-133, with a fission yield of 6.62 per cent, a half life of 22.4 hr, and an average beta energy of 0.4 Mev, is suggested as the principal contributor to early thyroid burden.

4.2.4 Interaction of Time and the Position of the Sampling Site Within the Fall-out Pattern upon the Accumulation of Fission Products

Several residual fall-out patterns were defined, and samples were taken along the midline of contamination in October 1955 (see Sec. 2.3.2). The biological accumulation of fission products existing at that time is summarized in Table 3.23. Figure 4.13 summarizes the results from one pattern dominated by the Met shot fall-out pattern. These data appear representative of the other residual fall-out patterns. The environmental contamination, a measure of gross residual fall-out contamination, decreased sharply with distance. The gross beta-gamma activity in jack rabbit bones sampled along the midline of residual fall-out increased to approximately 134 miles, and then it decreased slightly and leveled off. The radiation levels above normal that occurred in the bone were estimated by the presence of radiostrontium. The peaking of the radioactive content of the bone at 134 miles appeared more specifically to be attributable to the relatively heavy concentration of Sr^{89}.

This was not the first time that such a phenomenon had been observed. In May 1954, 1 year following the Upshot-Knothole test series, another residual fall-out pattern was studied to a distance of 130 miles from GZ.[7] Once again, soil contamination was shown to fall off sharply, whereas the burden of radiostrontium in jack rabbit bones increased to a maximum at approximately 130 miles from GZ.

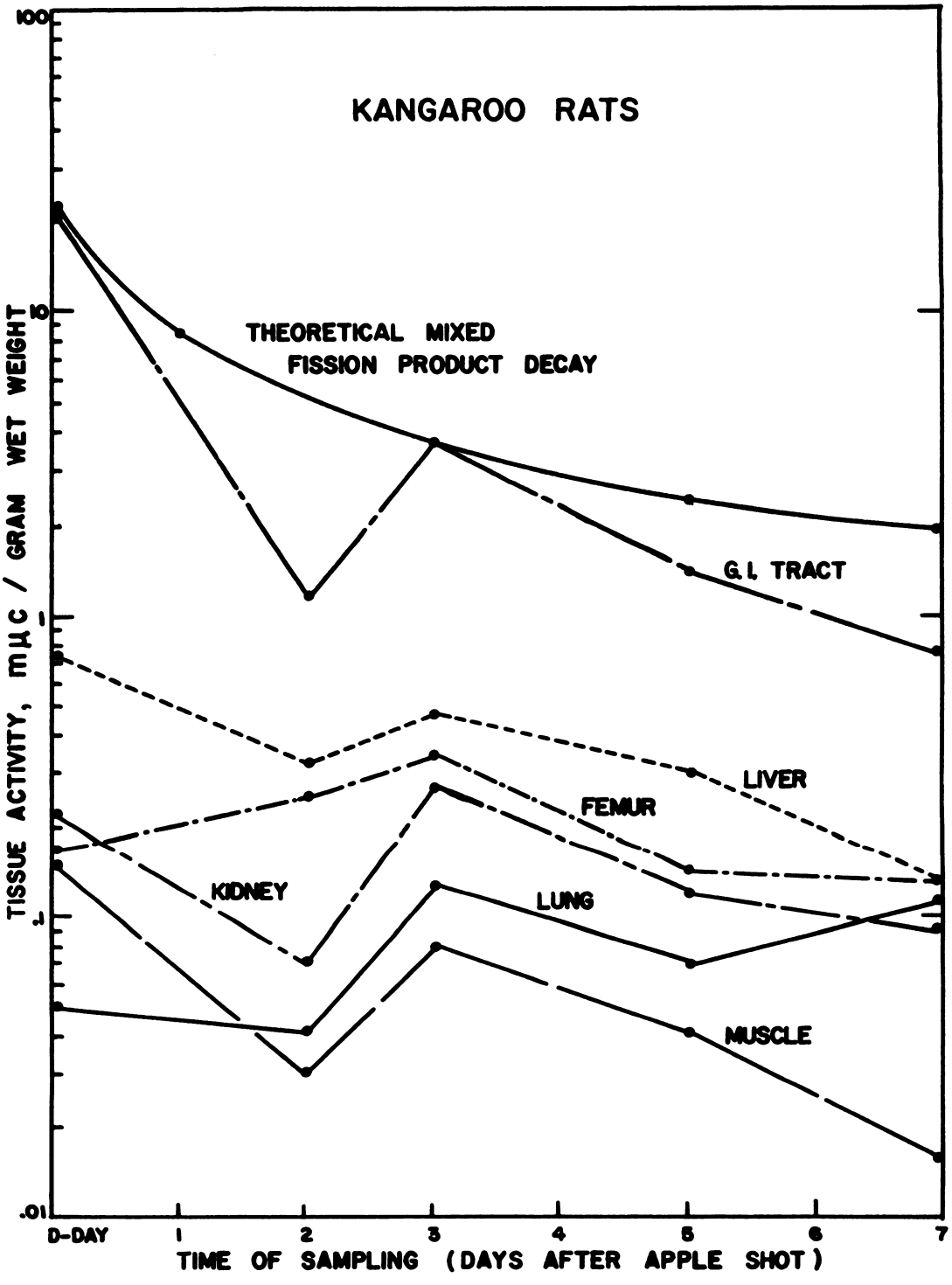


Fig. 4.10 — Persistence of fission products in the tissues of kangaroo rats serially sampled from the midline of Apple I shot fall-out, 12 miles from GZ.

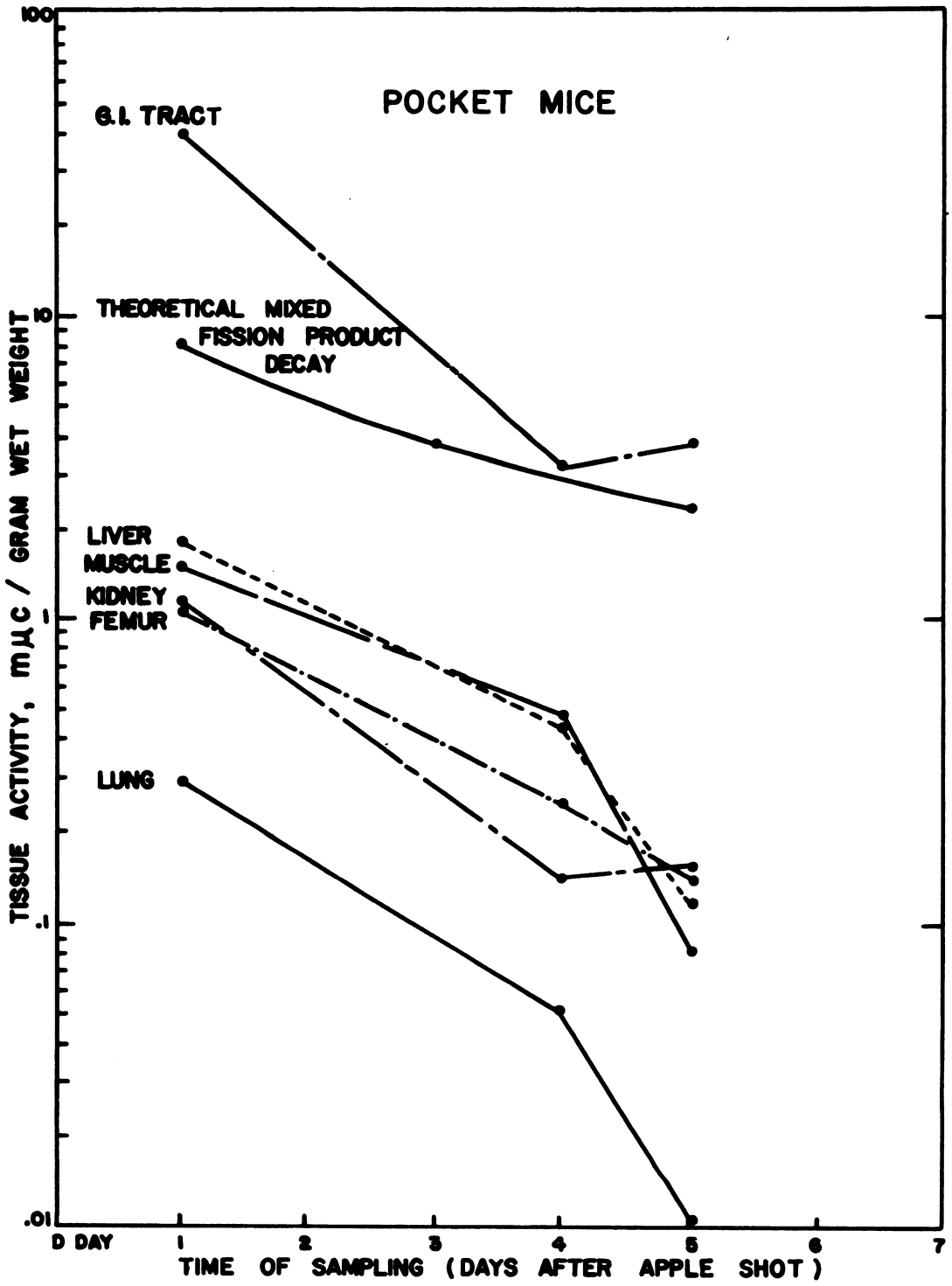


Fig. 4.11 — Persistence of fission products in the tissues of pocket mice serially sampled from the midline of Apple I shot fall-out, 12 miles from GZ.

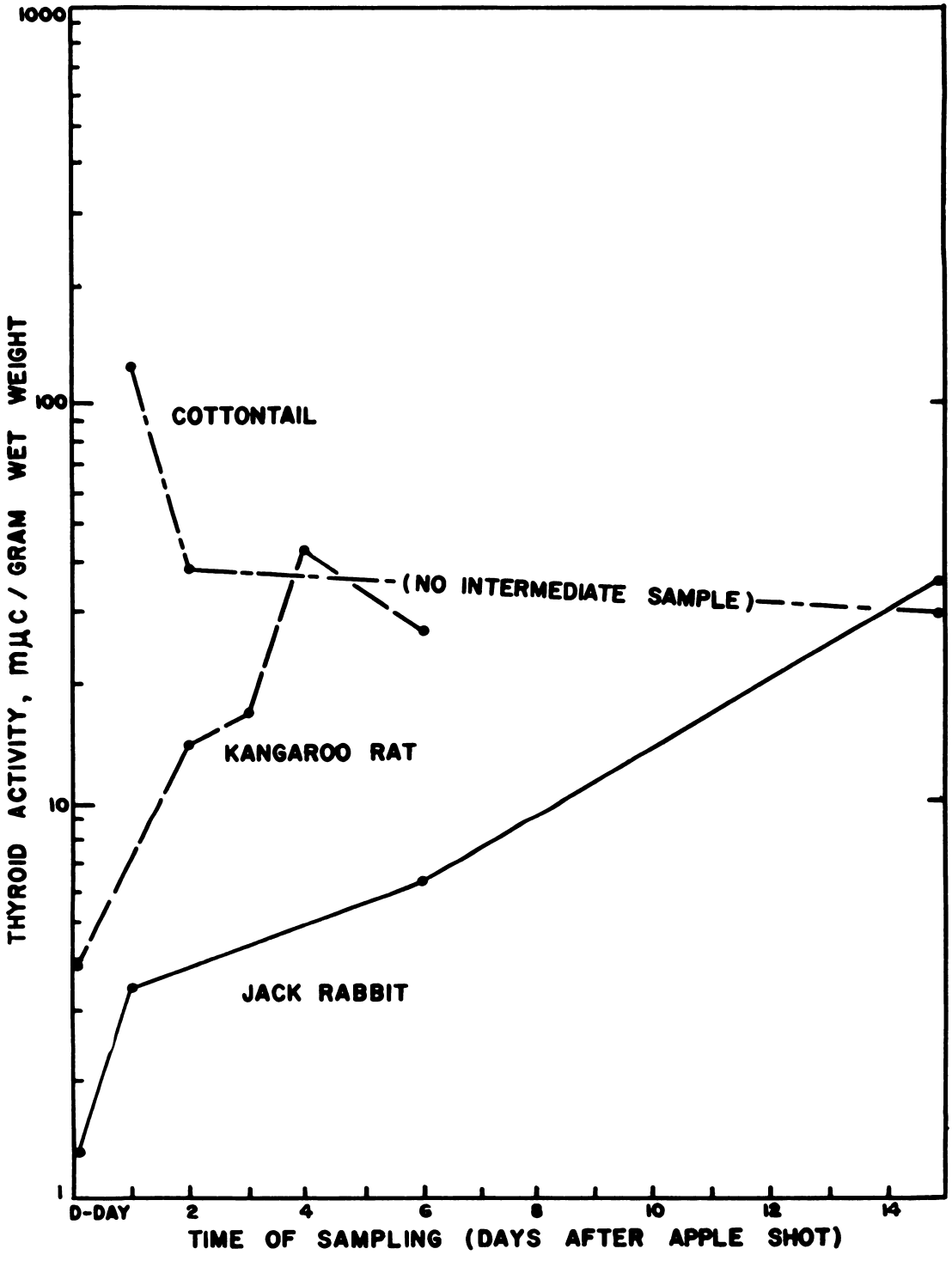


Fig. 4.12—Persistence of radioiodine in the thyroids of native animals serially sampled from the approximate midline of Apple I shot fall-out, 12 miles from GZ.

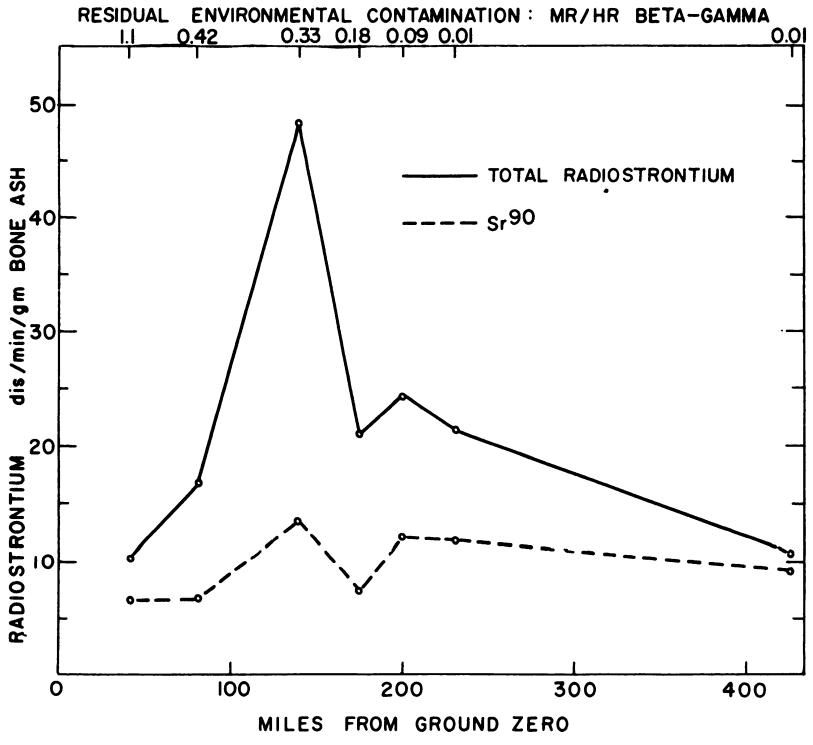


Fig. 4.13—Occurrence of radiostrontium in the bones of jack rabbits sampled along the midline of residual fall-out contamination 6 months following fall-out from Met shot.

Remember that, with respect to the radioiodine data, the peak concentration in the thyroid occurred at about 60 miles. The maximum concentration of radiostrontium in bone occurred at about 130 miles; and, in both the 1954 and 1955 instances, the distances are remarkably similar, considering the great differences in the conditions of detonation.

Another parameter is needed to explain these observations. This parameter, which also influences the biological fate of radioactive fall-out, can be assumed to be the time necessary for the parent fission products to decay into the daughter products measured in the samples. The radioactive half life of the precursor and its chemical characteristics will determine how the daughter product is finally distributed as fall-out material. The question as to the fate of other specific fission products (such as cerium, cesium, ruthenium, and zirconium) is proposed for study during the next weapons testing program.

4.3 SUMMARY OF FACTORS INFLUENCING THE ACCUMULATION OF FISSION PRODUCTS BY ANIMALS

In summary, we can trace the biological fate and persistence of radioactive fall-out in animals as follows: First, during participation in various nuclear testing programs, it has been found that the predominant size of fall-out particles greater than 100 μ in diameter decreases with distance from GZ, whereas the less than 100-μ material does not decrease but remains the same or increases with distance up to 200 miles from GZ.[8] Furthermore, the smaller size material tended to be more soluble and therefore potentially more available to the biological cycle.[1] Second, the majority of particles retained by foliage were below 44 μ in diameter, having an average size of approximately 20 μ.

A feasible explanation is that the accumulation of fission products by grazing animals is related to particle size and that, because the plant acts as a selective collector of very small fall-out particles, the intake of radioactive debris by animals during grazing tends to be similar over a great distance and appears to be independent of total fall-out. The amount of any specific isotope present is dependent upon the physical and chemical behavior of its iso-

topic precursor during fall-out particle formation. Therefore, the amount of any specific isotope (such as strontium or iodine) at any particular location within the fall-out pattern will be highly variable, and the occurrence of areas in which the biological accumulation of that isotope is high is to be anticipated.

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Chapter 5

SUMMARY

The levels of radioactive contamination of biological materials sampled during Operation Teapot were generally lower than the levels measured from equivalent locations during Operation Upshot-Knothole. The conclusions drawn during Operation Upshot-Knothole still appear to be valid, namely, that portions of radioactive fall-out will be metabolized by animals and that the biologically available fraction of fall-out does not necessarily correlate with the amount of total environmental contamination by radioactive fall-out.

During Operation Teapot, the biological accumulation of fission products derived from nuclear detonations was studied as a function of (1) the distance of the sampling site from GZ, (2) radioactive particle-size distribution, and (3) fractionation of all fall-out material as it may vary with distance from GZ. This included studies on (1) the persistence of fission products in plants and animals living in contaminated environments, (2) the availability of fall-out material to plants and animals under various conditions of contamination, (3) evaluation of inhalation as a significant phenomenon in the uptake of fission products in actual fall-out areas, and (4) the determination of the percentage distribution of the total-body burden of certain isotopes in the tissues of animals exposed to fall-out.

The data discussed in this report are summarized as follows:

1. The activity measured in plant samples collected from fall-out areas is principally accounted for by external contamination by radioactive fall-out particles less than 44 μ.

2. The degree of plant contamination by radioactive fall-out is a function of the mechanical-trapping characteristics of leaf surfaces and the mechanical distribution of the less than 44-μ-size particles within a distance of 100 miles from GZ.

3. Fall-out particles less than 44 μ in diameter are biologically significant because of their high degree of retention on the foliage of forage crops and relatively high solubility.

4. The degree of contamination of plant foliage is related to such conditions of detonation as tower height and particle sizes of the surface soil at GZ.

5. The radioactive fall-out material on plant foliage is persistent, as is evidenced by the radioactivity remaining on leaves even after washing in 5 per cent Versene and 0.1N HCl or by the mechanical shaking brought about by severe windstorms.

6. Forage crops cannot be completely decontaminated by washing, nor is it practical to do so. Normal washing procedures used in cleaning fruits and vegetables before packaging, shipping, and storing for human consumption, however, will aid greatly in removing fall-out contamination, as does the common practice of peeling or scraping foodstuffs during meal preparation.

7. An average of 21.6 per cent of the contamination on leaves is soluble in 0.1N HCl, which suggests that a similar percentage of the quantity ingested by grazing animals would go into solution in the digestive tract.

8. Small amounts of radioactive materials are absorbed by plants from contaminated soils for about the first year after fall-out deposition. Externally contaminated cover crops and dry organic materials incorporated into soils are sources of radioactivity for successive crops grown on these soils.

9. Intensive cropping is neither efficient nor effective in removing fall-out contamination from soils. Under the conditions of the experiment, much higher levels of contamination from fall-out material of the type produced by Apple II shot are necessary before crop plants will take up appreciable amounts of fission products.

10. Cover crops partially shield the soil surface from fall-out contamination. This is particularly true for fall-out particles less than 44 μ in diameter.

11. The tissue burdens of fission products in animals sampled from fall-out-contaminated environments tend to decrease with distance from GZ in a manner similar to the degree of plant contamination. The activity per unit weight of the femur, however, tends to remain fairly constant to a distance of 140 miles from GZ.

12. The thyroid shows a greater tissue burden of radioiodine at 60 miles than at either 12 or 140 miles from GZ. The thyroid is a qualitative indicator as to whether or not biologically available fall-out is present during the first week or two following detonation.

13. Iodine-133 is believed to contribute largely to the thyroid burden during the first 3 days following the detonation.

14. The relative decrease in tissue burdens of fission products in native animals serially sampled from the same fall-out-contaminated environment over a 15-day period in most cases did not markedly deviate from the environmental beta decay of mixed fission products. The radioactivity per unit weight of femur, however, gradually increased until 3 days post-shot, and then it decreased. The thyroid activity continued to rise throughout the 15-day sampling period.

15. The accumulation of fission products in the skeletons of jack rabbits sampled between 6 and 7 months following fall-out was still two to five times higher than normal. The amount of radiostrontium in the bone had increased two to six times over the values determined between D+2 and D+10 days, indicating the effects of chronic exposure.

16. The peak concentrations of radiostrontium in bone measured along the midlines of residual fall-out 6 to 7 months after fall-out were at distances between 96 and 134 miles from GZ.

17. Data suggest that inhalation, as compared to ingestion, is a negligible path of uptake of fission products during or after fall-out contamination. The extent to which fission products may be accumulated through inhalation of fall-out is still open to speculation.

18. In most cases, the close correlation between the relative tissue activity and the radioactive content of the digestive tract suggests that ingestion is the principal source of tissue activity. In the population of animals, the data indicate that a rapid equilibrium between the absorbed radioactivity and that passing through the gut may have been established within the first 2 days following fall-out.

19. The accumulation of fission products by grazing animals is related to particle size, and, because the plant acts as a selective collector for very small fall-out particles (less than 44 μ in diameter), the intake of radioactive debris by animals during grazing tends to be similar over a great distance and appears to be independent of total fall-out.

20. The amount of any specific isotope present is dependent upon the physical and chemical behavior of its isotopic precursor during fall-out particle formation. Therefore, the amount of any specific isotope at any particular location within the fall-out pattern will be highly variable, and the occurrence of areas in which the biological accumulation of that isotope is high is to be anticipated.